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WEEKLY 8 April 2023

SPECIAL ISSUE

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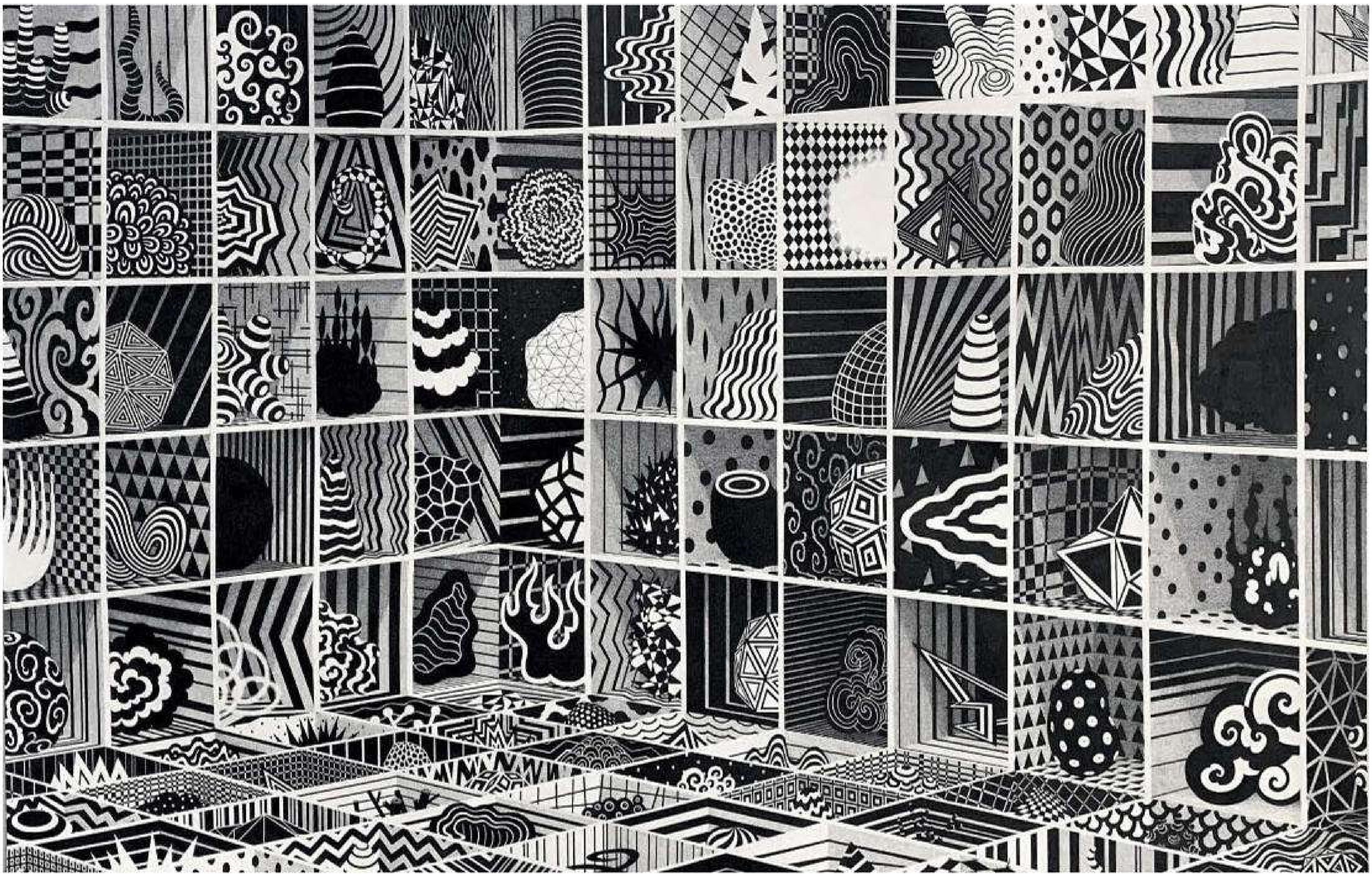

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New Scientist

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Subscriber-only event

A Wonderful Life: How to live a life full of meaning

Join philosopher and psychology expert Frank Martela to tackle the grand question of the meaning of life. He will explore what this actually means and some practical steps you can take to experience more meaning in your own life. Online at 6pm BST (1pm EST) on 18 April and on demand.

newscientist.com/events

Tour

Explore the science of London along the river Thames

Immerse yourself in London's scientific sites. Led by Blue Badge Tourist Guides and accompanied by *New Scientist*'s Rowan Hooper, David Stock and Emily Wilson, you will visit sites including the London Wetland Centre and the Royal Observatory, Greenwich. The five-day tour begins on 2 July and costs £2165.

newscientist.com/tours

Podcasts

Weekly

Podcast editor Rowan Hooper visits London's Natural History Museum to see the skeleton of *Patagotitan mayorum* – one of the largest land animals ever – and discover how sauropod dinosaurs got so big. Also on the show, the oldest black hole found and an interview with Richard Fisher, author of *The Long View: Why we need to transform how the world sees time.*

newscientist.com/podcasts

NATIONAL MARITIME MUSEUM

Thames trip This observatory is a science highlight on London's river

JONAS GRATZER/LIGHTROCKET VIA GETTY IMAGES

Seaweed harvest Novel solutions for storing carbon in the oceans

Video

Soapy science

Watch how two "kissing" soap bubbles interact as they are squished together and pulled apart. Scientists are keen to see what happens when different sized bubbles interact, sometimes slipping across one another, separating or forming a single bubble. They hope this will help predict how packing materials deform when touched.

youtube.com/newscientist

Newsletter

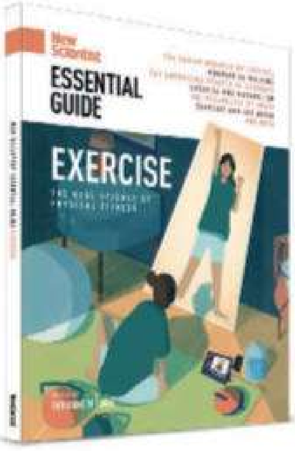
Fix the Planet

This week, reporter Madeleine Cuff is looking at the emerging sector of ocean carbon storage. Is it the best hope for staving off the climate crisis or a Wild West for carbon removal? She explores radical solutions from seaweed farming to adding iron to "fertilise" ocean waters

newscientist.com/fix-the-planet

Newsletter

> "Researchers say adding masses of baking soda to the seas to store carbon would do no harm"



Essential guide

Exercise is the best medicine. It keeps body and mind in prime condition and adds years to our lives. But why do so few of us get enough? This *New Scientist Essential Guide* offers some clues. Available to download in the *New Scientist* app or to purchase in print from our shop.

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OWN YOUR MIND BUSINESS

Discover what makes you tick with How We're Wired, a brand new podcast that looks at what happens inside your brain – from before you were born through to death.

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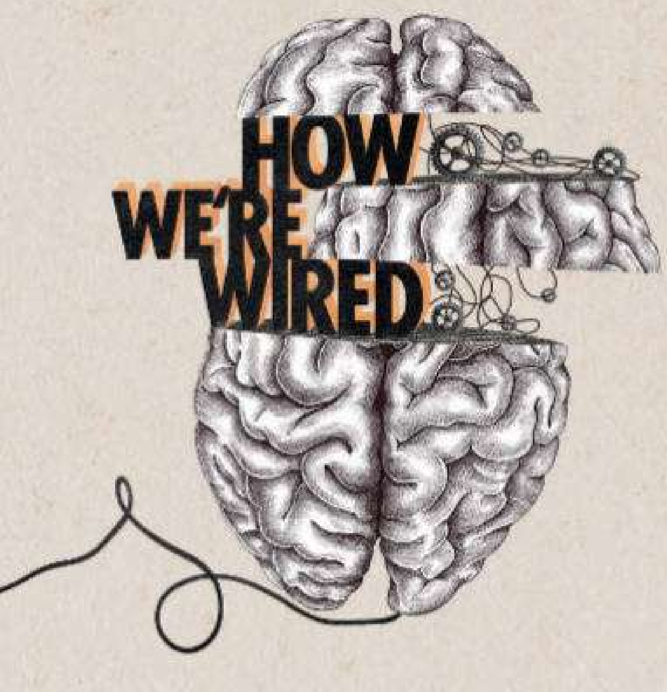

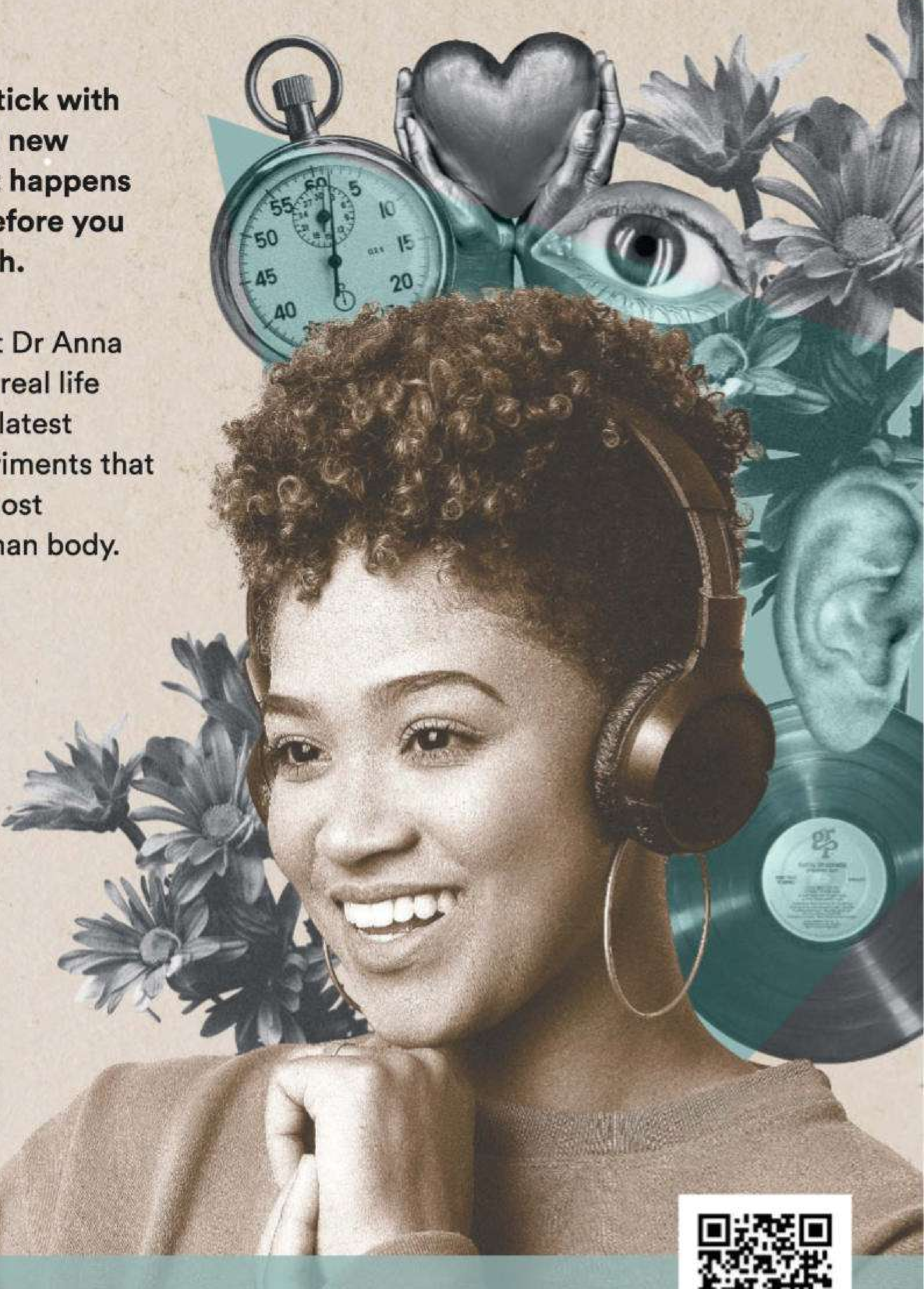

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Subatomic safari

Explore the quantum world with our grand tour of reality at its smallest scales

QUANTUM mechanics is ultimately just a physical theory, albeit a hugely successful one. It precisely and accurately describes the way things behave at the smallest scales. Yet the word "quantum" is supremely evocative. The infinitesimal realm of subatomic particles and forces it brings to mind has a reputation for strangeness – a place that mere mortals fear to tread, never mind understand.

We are told that particles are fields and vice versa, that uncertainty reigns and that wave functions collapse vague clouds of probabilities to manifest the distilled reality we know. It can be tempting, in the face of such revelations, to wheel out the notorious meme from physicist Richard Feynman: "Nobody understands quantum mechanics."

All of which is true, in a sense. But it would be a mistake to conclude as a result that the subatomic world is somehow off-limits. On the contrary, its inherent strangeness and the conundrums it contains are precisely what makes it such a thrill to discover. And it is in that spirit of exploration that we present our 10-page inventory of the quantum realm, starting on page 36.

> "The quantum world is less confusing than you think, as long as you abandon your intuitions"

Last year, with our inventory of the universe issue, we explored the large-scale cosmos all the way out to its furthest reaches. This time, we are heading in the opposite direction, to the very smallest of the small. You can think of it as a subatomic safari, or at least a field guide to the denizens of the microworld. Not only will you discover the particles and forces we know about, you will also make sense of their strange behaviours and the laws that govern them. You will meet the dazzling cast of hypothetical particles that physicists suspect could solve cosmology's biggest mysteries, as well as some of the stranger things that they think could yet be found at an even deeper level of reality.

We hope you will find it an exhilarating tour. And, as you will see, the quantum world is less confusing and more delightful than you might think, just as long as you enter prepared to abandon your intuitions. ▮

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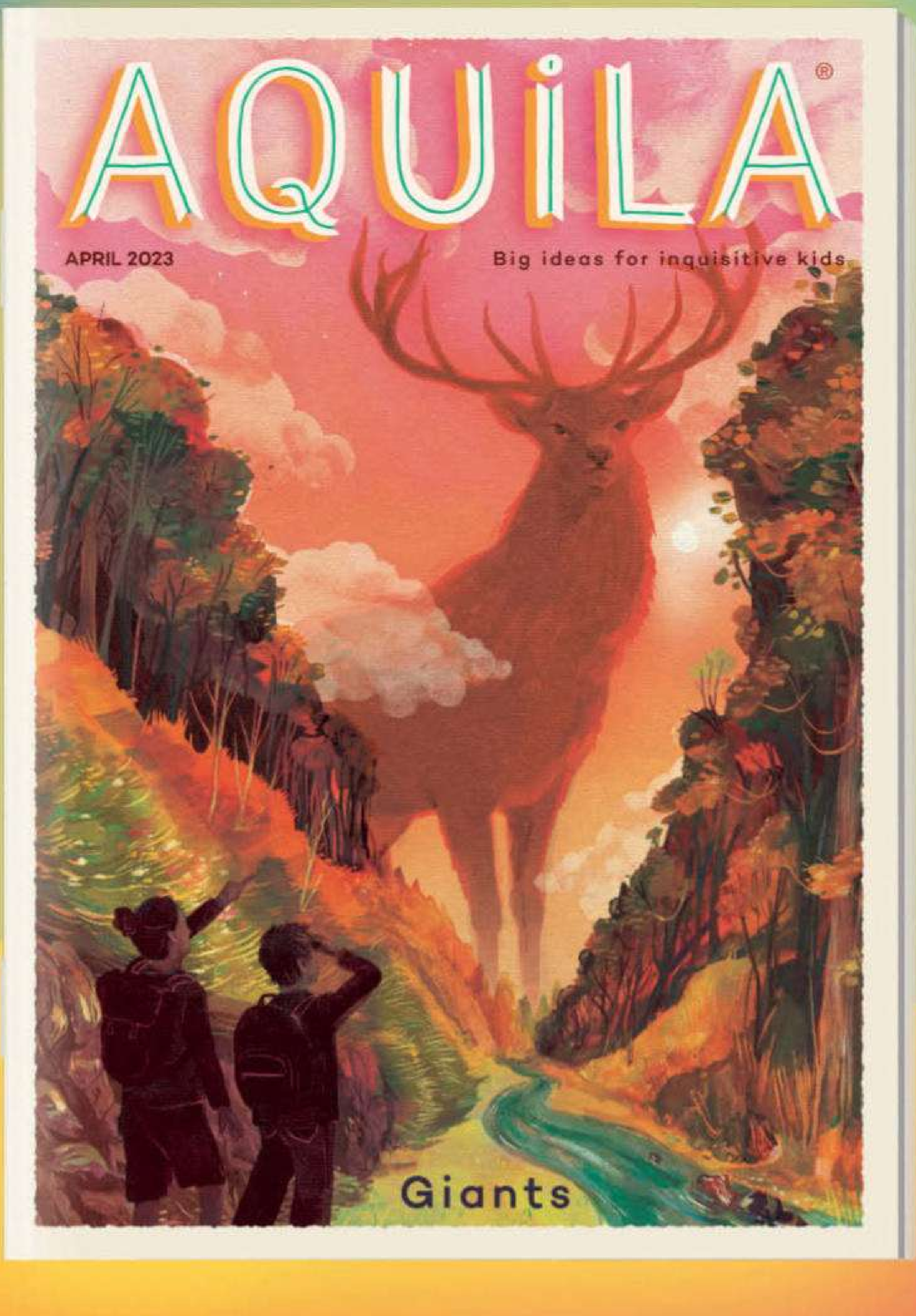

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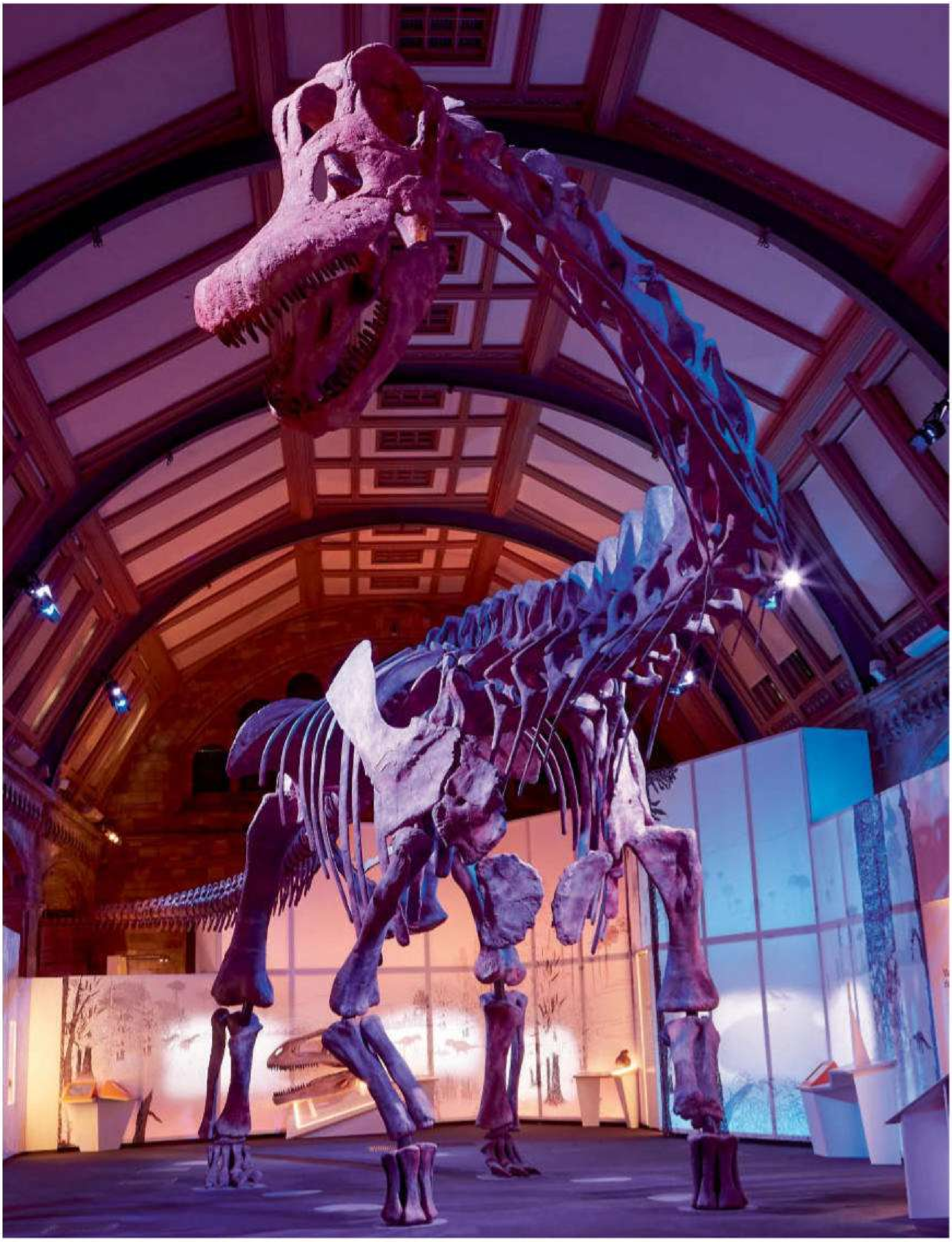


LUCIE GOODAYLE/NATURAL HISTORY MUSEUM

Palaeontology

A giant of the dinosaur era

Meet *Patagotitan*, one of the largest animals to have thundered across Earth. At more than 37 metres long, this beast would have weighed in at almost 60 tonnes when alive – an immense weight that was supported by vast thigh bones over 2 metres tall. This cast, made using a model skeleton and real fossils, is now on display at the Natural History Museum in London.

Astrophysics

Information can survive a black hole

A decades-old paradox uncovered by Stephen Hawking may be solved

Leah Crane

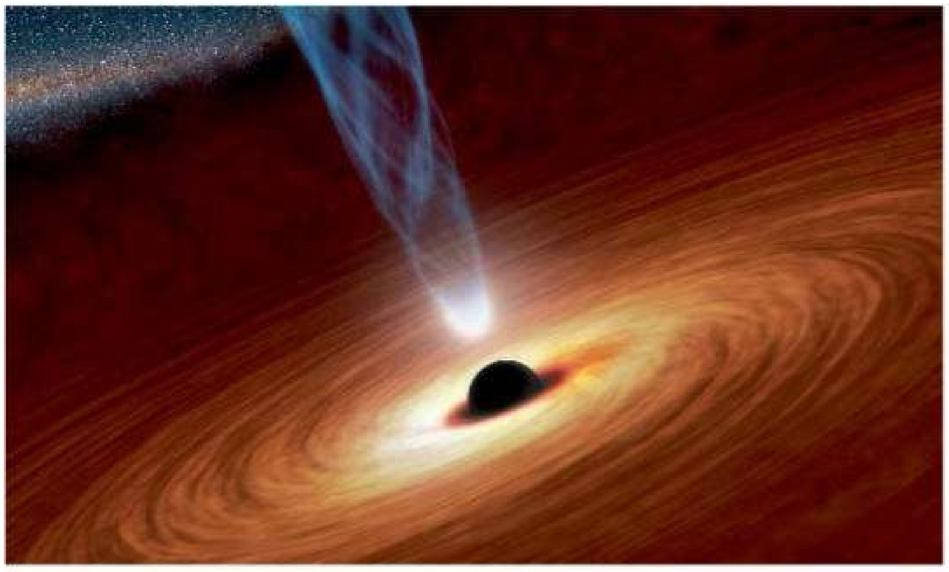
BLACK holes have an information problem. According to the laws of quantum mechanics, information about the state of a closed system can't be destroyed, but black holes seem to obliterate it. Researchers have been trying for decades to solve this so-called black hole information paradox, and now one team claims to have finally figured it out.

The paradox was born in the 1970s when Stephen Hawking calculated that black holes should slowly evaporate by emitting random particles in what is now called Hawking radiation. This suggests that any information-containing matter that falls into a black hole would be destroyed as it eventually shrinks to nothing. But the laws of quantum mechanics require that if you know the state of any closed system at one time, you should be able to work out its state forwards or backwards in time. If Hawking radiation is indeed random, that becomes impossible.

"We have redone the calculation that Hawking did in the 1970s, but we have taken into account quantum gravity," says Xavier Calmet at the University of Sussex in the UK. "The black hole information paradox is solved now, and we understand the physics of it."

In earlier work, he and his team found that when they applied quantum mechanical corrections to calculations of stars evolving into black holes, the black holes' gravitational fields would preserve information about what fell in.

An artist's impression of the black hole in the heart of spiral galaxy NGC 1365



NASA/JPL-CALTECH

Now, they say they have worked out what happens to that information as the black hole evaporates.

This is difficult to solve because of the way the leaking information is distributed. "It comes out again so slowly, and in such small pieces, that you have to dig really deep into the theory" to figure out how the information that fell in relates to what is coming out, says Neil Lambert at King's College London.

Calmet and his team calculated that the gravitational field of a black hole should slightly modify the energy spectrum of Hawking radiation that emerges. "It's a tiny effect, but it means that the spectrum contains information," he says. Any order in the spectrum of Hawking radiation could preserve information (*Physics Letters B*, doi.org/j4qz).

However, not everyone is satisfied yet. "This doesn't fix the problem," says Daniel Harlow at the Massachusetts Institute of Technology. Objections largely boil down to the idea that, ironically, this idea doesn't have enough information about how exactly the information is preserved, particularly when the black hole evaporates completely. "I don't think it's precise enough," says Lambert.

Testing this work will be difficult because Hawking radiation is such a minuscule effect. "Practically, honestly, it's not measurable – we've never seen Hawking radiation from a real black hole," says Calmet. "But there are ways to build analogues to black holes where you can model Hawking radiation." Perhaps these analogues will provide resolution, he says. ▮

Health

Oxygen-sucking battery rids mice of breast cancer

A BATTERY that consumes oxygen and runs on salt water has helped to shrink or eliminate cancer tumours in mice in two weeks.

As most tumours grow, they use up oxygen from surrounding, non-cancerous tissues, making the tumours' cells oxygen-free, or hypoxic. One drug class, hypoxia-activated prodrugs (HAPs), seeks to exploit this trait by only killing hypoxic cells, so healthy cells are less affected. No HAPs are approved for clinical use due to limited evidence of their effectiveness.

Now, Fan Zhang at Fudan University in Shanghai, China, and his colleagues have developed a self-charging, implanted battery that runs off salt water injected around it, causing the battery to produce very low voltage electricity and to consume oxygen. By creating a hypoxic environment, the battery should optimise the HAPs' action.

Zhang and his team induced breast cancer in 25 mice. They then implanted the battery into five of the mice's armpits and gave them HAPs. The other mice either received no treatment, HAPs only, an implanted battery that didn't work or just the working battery, which runs for up to 500 hours in mice.

Fourteen days later, the tumours had shrunk by an average of 90 per cent across the five mice given the battery and HAPs, and they vanished completely in four of these mice (*Science Advances*, doi.org/j4wf). The tumours remained the same size or grew in the other mice.

"After 14 days, the tumours had vanished completely in four of the five treated mice"

While the battery caused no adverse health concerns in the mice, the safety bar is set higher for people, so further research is needed to ensure the battery is compatible with human tissue, says Zhang.

Randall Johnson at the University of Cambridge says that inducing hypoxia in a tumour can increase the risk that the cancer will spread. While this didn't appear to occur in these mice, the costs and benefits of the battery's use in people needs to be assessed before any human treatment, he says. ▮

Alex Wilkins

Chemistry

Material impervious to radiation could be used in spaceships

Alex Wilkins

A CRYSTAL that can resist incredibly high doses of radiation could be used to build durable electronics for space travel or nuclear reactors.

When particle radiation hits a semiconductor – the conductive materials used to make electronics – it can knock atoms out of place, changing the material's properties. This means that electronic devices in high radiation environments must be made more robust. One compound that has shown promise is gallium oxide, a semiconductor that can take five different crystalline forms.

Now, Andrej Kuznetsov at the University of Oslo in Norway and his colleagues have found that when two of gallium oxide's crystal forms, called the beta and gamma phases, exist in the same material side by side, the combination can withstand extremely high doses of heavy ion radiation, which are highly energetic charged particles typically ejected from stars as cosmic rays.

"What we discovered is really a new sort of material that tolerates unprecedented amounts of radiation damage," says Kuznetsov.

To make the crystal combination, the researchers separately fired heavy ions of nickel, gallium, gold and neon at gallium oxide in its beta phase, which pushed parts of it into the gamma phase. They continued until the crystal reached a stable mix of the two types.

Kuznetsov and his team then increased the number of ions by hundreds of times. This took the radiation way beyond the level seen in nuclear reactors or cosmic rays, and there was no structural change.

Exactly why this happens is unclear, but Kuznetsov thinks it is related to the many different locations a displaced gallium atom can jump to within the crystal lattice without disturbing the overall structure (arxiv.org/abs/2303.13114). ▮

Neuroscience

A mental workout could help clear out your brain's waste

Clare Wilson

THE brain's "waste disposal system" may kick in after intense neural activity – and it might be possible to turn on the process intentionally.

Until recently, this system was thought to activate only during sleep, but now researchers have seen it ramping up in people after they watch flickering chequerboard patterns on a screen.

"Much of how the brain's waste disposal system functions in people is still unclear"

The finding provides a tantalising hint that people may be able to deliberately flush out waste products from their brain by staring at intense visual stimuli, says Laura Lewis at Boston University in Massachusetts.

"The real surprise was that they found it in awake people," says Edoardo Rosario de Natale at the University of Exeter in the UK, who wasn't involved in the work.

The brain's waste disposal system involves cerebrospinal fluid (CSF) being pumped into the brain and leaving through a network of fine tubes called the glymphatic system, which was only discovered in 2012.

Animal research suggests the fluid flushes out waste products made by brain cells, including harmful compounds that may be involved in Alzheimer's disease and Parkinson's disease, such as beta-amyloid and alpha-synuclein.

Since the glymphatic system's discovery, there has been a surge of research aiming to understand how boosting fluid flow could help improve brain health, but much of how the system functions in people is still unclear.

The researchers took advantage of a new brain-scanning technique, using existing magnetic resonance imaging machines, that highlights any CSF that has newly entered into the fourth ventricle of the brain, a cavity at the base of the head. Fluid that enters this chamber drains out through the glymphatic system.

They asked 20 volunteers to watch a screen inside the scanner that displayed a pattern known to cause high brain activity: a flickering black-and-white spiral chequerboard. The display was turned on and off at 16-second intervals for about an hour, apart from during short breaks.

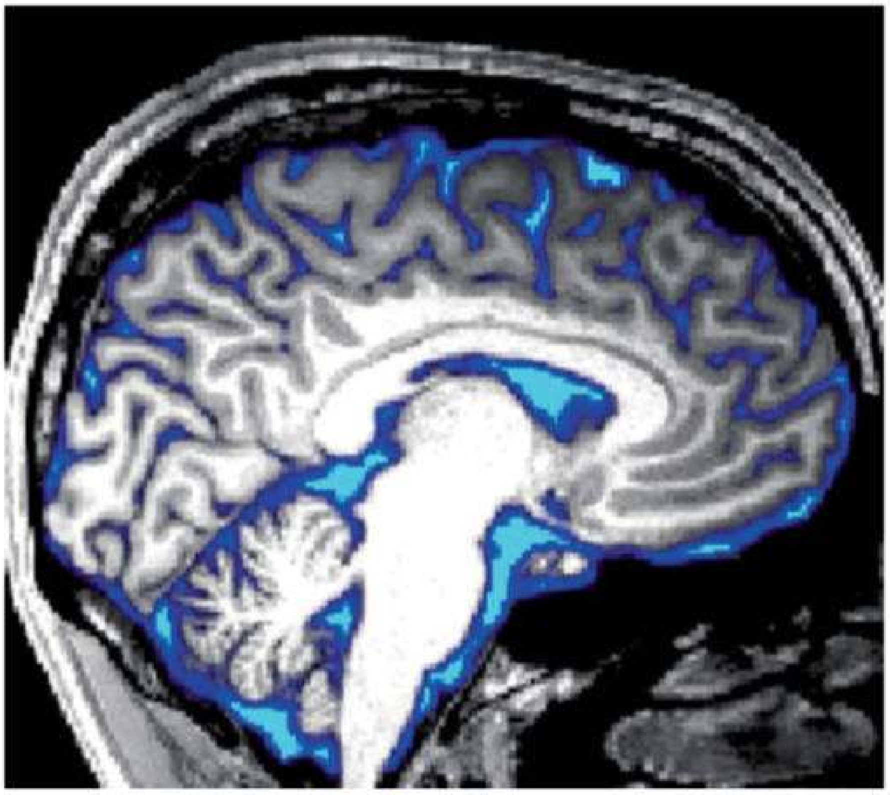
Fluid entering the brain

When the pattern was shown, this caused a rise in blood flow to the brain's visual centres, as expected. When the screen went dark, blood flow reduced and CSF flow into the brain increased (*PLoS Biology*, doi.org/gr2q5c).

The brain-scanning technique couldn't reveal if the fluid left through the glymphatic vessels, nor if there was a reduction of waste products within the brain. These are questions that need to be tackled next, says Rosario de Natale. "This is opening a new door."

"It's still an open question whether the fluid goes directly into the brain tissue or if it sloshes around in the ventricle. But we definitely think that it has an effect on fluid in the rest of the brain," says team member Stephanie Williams, also at Boston University.

"We're very interested now to understand the effect of these changes in fluid flow and how it intersects with brain health," says Lewis. ▮


STEPHANIE D. WILLIAMS (CC-BY 4.0)

Cerebrospinal fluid (blue) seen on an MRI scan of the brain

Health

A childhood like no other

Australia's policy of detaining child asylum seekers, in some cases for years, has had long-lasting effects on their health, finds **Alice Klein**

CHILDREN who were locked in Australia's immigration detention centres in the past decade have high rates of mental health conditions, developmental issues and nutritional deficiencies.

"We'd like policy-makers to recognise that detention is harmful for children and they should not be detained under any circumstances," says Shidan Tosif at the Immigrant Health Service at the Royal Children's Hospital Melbourne, Australia, who led a study of these children's health.

Australia has a policy of detaining all asylum seekers who arrive without a valid visa while their claims are reviewed. Adults are mostly housed in high-security immigration detention centres. Under Australian law, children should only be held in these facilities as a last resort and should preferably be detained in community housing with their families.

However, from 2012, Australia began keeping hundreds of children in detention centres for long periods, often for years, after there was a surge in the number of asylum seekers arriving by boat.

Tosif and his colleagues reviewed the medical records of 239 of these children who were referred to the Immigrant Health Service, which provides medical and mental health care to asylum seekers and refugees. The children attended the service between 2012 and 2021, either while they were still in detention, which required them to be brought in by guards, or after they were released.

The children came from 15 countries, the most common being Iran. The average time they spent in detention was seven months for those held in facilities on Australia's mainland and more than four years for those held in offshore detention centres on Nauru in Micronesia and Manus Island in Papua New Guinea.

JAMES ROSS/EPA-EFE/SHUTTERSTOCK

A rally against child detention, in Melbourne, Australia, in June 2021

Overall, 60 per cent of the children had a nutritional deficiency such as low iron or vitamin D. None received any routine childhood vaccines in detention, meaning 71 per cent were behind on immunisation schedules. One-fifth also had untreated latent tuberculosis.

Three-quarters of the children had developmental differences, including autism or learning difficulties, and 62 per cent had mental health problems, including anxiety, depression or post-traumatic stress disorder. This was more than four times higher than the rate of mental health conditions in Australian children. Many experienced nightmares and 10 per cent had self-harmed (*PLoS One*, doi.org/j4pr).

"We'd like policy-makers to recognise that detention is harmful for children and should not happen"

This finding is consistent with anecdotal reports from a small number of paediatricians who were allowed to visit Australia's immigration detention centres.

After seeing the Nauru detention centre in 2014, David Isaacs at the Children's Hospital at Westmead in Sydney, for example, described a 6-year-old girl who had tried to kill herself and a 15-year-old boy who had self-harmed.

Elizabeth Elliott and Hasantha Gunasekera, also at the Children's Hospital at Westmead, visited a detention centre in Australia's Northern Territory in 2015 and told the Australian Human Rights Commission (AHRC) that the detained children were among the most traumatised they had ever seen, with many talking openly about suicide.

Many of the children had already experienced trauma before coming to Australia, but locking them in detention centres harmed them further because of the poor living conditions and restrictions on their movement, education and play, says Tosif. The AHRC described detained families living in tents surrounded by tall, wire fences and a child playing with cockroaches.

Adding to the problem was the profound uncertainty the children and their families felt because they didn't know how long they would be detained for, says Tosif.

The number of children held in Australian immigration detention centres peaked at almost 2000 in July 2013. Since late 2014, the government has gradually moved children out of these centres, with the last two released in 2021.

The released children were initially moved to community detention or given temporary visas, which "continued the uncertainty", says Tosif. But since February this year, some have been able to apply for permanent visas.

To prevent children from being held in prolonged detention again, Rebecca Eckard at the Refugee Council of Australia, an independent advocacy organisation, says the government should legislate so children can be held in detention centres for no longer than 72 hours before they must be moved to community detention.

A spokesperson at the Australian Department of Home Affairs says that the Australian government is "committed to keeping children out of immigration detention centres" and "has zero tolerance for any form of abuse, neglect, maltreatment or exploitation involving children".

Tosif says some children who experienced detention will have lasting health consequences. "We do find if they get a permanent visa, it really improves their outlook on life, but issues can surface later on after childhood trauma," he says. "That is something we're monitoring." ▮

Need a listening ear? UK Samaritans: 116123 (samaritans.org). Visit bit.ly/SuicideHelplines for hotlines and websites for other countries.

The UK's five big climate bets

Reaching net-zero carbon emissions by 2050 will require huge transformations across the whole of the country. **Madeleine Cuff** examines the government's key plans

THE UK government has released the detailed calculations behind its plan for reaching net-zero carbon emissions by 2050. The *Carbon Budget Delivery Plan*, published on 30 March, provides an exhaustive list of how much the government expects individual policy measures to contribute to emissions cuts. With the uncertainty involved, these policies are essentially big bets on the future of energy use in the UK, with the hope that they will get the country well on the way to net-zero emissions by the end of the 2030s.

New Scientist has examined the top five carbon-cutting moves in the UK's plan, which are expected to deliver 40 per cent of the emissions cuts needed by 2037, according to government estimates. But experts have voiced concern that the calculations in the report represent wishful policy-making rather than realistic predictions.

Decarbonising power

The UK aims to decarbonise its power grid by 2035 by rolling out new nuclear power stations, hydrogen, solar and carbon capture technologies and vast amounts of offshore wind.

In total, this is expected to cut emissions by 2.7 megatonnes of CO_2 equivalent ($MtCO_2e$) each year from now until 2027, 6.7$MtCO_2e$ each year during 2028 to 2032 and 11.2$MtCO_2e$ each year during 2033 to 2037.

Of all the big bets, this one is probably the safest, says Jim Watson at University College London. But there are still risks, he says, such as uncertainties about novel small modular nuclear reactors. "We really don't know what their timescales and costs will be until developers start to build them," says Watson.

Creating a market for greenhouse gas removals

Technologies that trap and store carbon are central to the government's plans. Alongside schemes to establish carbon capture and storage "clusters" this decade, ministers also want to nurture a commercial market for these greenhouse gas removal methods.

There is a lot riding on this. Carbon savings from the greenhouse gas removal industry are projected to jump from 0.054$MtCO_2e$ a year during 2023 to 2027 to 23.4$MtCO_2e$ a year by 2033 to 2037.

But Stuart Hazeldine at the University of Edinburgh, UK, says that greenhouse gas removal is still a nascent industry, mostly dominated by start-ups. He estimates it could take 10 years for the sector to scale up dramatically, warning that the government's deployment predictions are "entirely speculative".

Decarbonising steel

The steel industry makes up about 14 per cent of industrial greenhouse gas emissions in the UK, but the government expects that by electrifying the steel-making process, using recycled steel and introducing hydrogen-powered iron-making, it can shave 10.3$MtCO_2e$ annually from the UK's annual carbon emissions by 2037. Delivering this won't be easy though, as the UK "has not yet piloted any new 'green' steelmaking technologies on a large scale", a UK parliament report noted in May 2022.

Mass deployment of heat pumps

There are, broadly, two options for decarbonising the heating of homes in the UK, which accounts for about 14 per cent of emissions: convert the gas grid to run on hydrogen, or switch out gas boilers for low-carbon heating like heat pumps.

The government's official climate adviser, the Climate Change Committee, advocates a rapid increase in the number of heat pumps deployed. Under a "high electrification" scenario, where little-to-no hydrogen is used for home heating, heat pump deployment would grow from 55,000 installations per year in 2021 to 1.9 million by 2035. This could save 15.4$MtCO_2e$ annually by 2037, according to the *Carbon Budget Delivery Plan*.

But current policies won't be enough to deliver such a huge increase in deployment, says Richard Lowes at the Regulatory Assistance Project. The government will need to do more to incentivise households to buy heat pumps, make the technology cheaper to run and eventually ban new gas boilers, he says.

40%

Share of required emissions cuts covered by the five big bets

2035

Year the UK aims to decarbonise its power grid by

32 million

Amount the carbon budget will miss its target by, in tonnes of CO_2

MARK WAUGH/ALAMY

Houses near Gwynt y Môr, a wind farm off the coast of Wales

Electric cars

With a 2030 ban on the sale of new petrol and diesel cars looming, the government wants to accelerate the pace at which people switch to an electric car. On 30 March, it detailed requirements for zero-emission vehicles to make up an increasing percentage of manufacturers' new car sales each year, starting at 22 per cent in 2024. This is expected to deliver carbon savings of 16$MtCO_2e$ per year by 2037. To support this, the government aims to have 300,000 electric vehicle charging points across the UK by 2030, but data published in January suggests that monthly installs need to jump by 288 per cent to meet this goal.

Big challenges

Despite the obstacles, the UK needs to overachieve on its ambitions. Even if all five of these big bets come off, the country is still set to fall just short of its carbon reduction target for 2033 to 2037. The current shortfall stands at 32 million tonnes of CO_2, more than a year's worth of emissions from London. ■

Health

Microplastics may increase how much fat the body absorbs

Grace Wade

TRACES of plastic in our food and water may increase how much fat we digest and absorb, potentially heightening the risk of obesity, heart disease and other conditions associated with consuming too much fat.

When plastics are degraded by sunlight, water, landfill incinerators and other processes, they can form microplastics – fragments less than 5 millimetres long. “As they degrade, they become smaller and smaller, going down into the nanoscale,” says Philip Demokritou at Rutgers University in New Jersey. “A nano is one-billionth of a metre. So, at that tiny of a size, you can’t even see it.”

The smaller the fragments become, the easier it is for them to leach into food and water. From there, they make their way into our bodies, though the exact amount we wind up digesting is unclear. Demokritou and his colleagues looked at how nanoplastics affect digestion using a model of the small intestine made from three different types of human epithelial cell, which line membranes.

The researchers added nanoplastics to a slurry that contained proportions of protein, fat, carbohydrates, sugar and fibre comparable to the average US diet. They then added heavy cream to boost the fat content. To simulate digestion, they passed this solution through three other liquids containing enzymes and molecules present in the mouth, stomach and small intestine.

The final product contained about 100 micrograms of nanoplastics per millilitre. Estimates of the average concentration of nanoplastics in food and water vary widely, but the researchers assume it is closer to 240 micrograms per millilitre. Demokritou and his colleagues coated the solution onto the small intestine model and measured the concentration and breakdown of fat 2 hours later. They found that the presence of nanoplastics boosted the breakdown of fat, increasing digestion by 33 per cent compared with a similar solution that didn’t contain any nanoplastics.

145%

Increase in fat absorption in model of small intestine containing nanoplastics

The nanoplastic mixture also increased the amount of fat the tissue absorbed by 145 per cent. The nanoplastics didn’t appear to be toxic to epithelial cells or to decrease gut permeability (*Environmental Science & Technology*, doi.org/j4kt).

“Our experience so far with microplastics is that they are not really toxic in the gut,” says Demokritou. However, he adds that “it’s very alarming that they can interfere with the digestion and absorption of nutrients”.

He believes this is because nanoplastics act like life rafts for fat molecules, increasing the surface area they can glom onto. This makes it easier for digestive enzymes to break down the fats, allowing the body to absorb more of them.

Luisa Campagnolo at the University of Rome Tor Vergata in Italy says that these findings in an organ model may not completely translate to humans. “But still, I think this paper is very important because it gives us a new perspective on the potential hazards of these particles.”

Demokritou says it is important to remember that not all microplastics are the same. Some have different properties, which may affect digestion. “There might be some differences between saturated and unsaturated fats [too],” he says. ▮

Nanoplastics may help high-fat foods break down more

PATRICK CIVELLO/SHUTTERSTOCK

Materials

Explosive can’t detonate unless filled with fluid

Karmela Padavic-Callaghan

AN EXPLOSIVE material made into a Swiss cheese-like structure could be safer to store and transport than conventional ones.

Alexander Mueller at Los Alamos National Laboratory in New Mexico and his colleagues created an explosive that cannot accidentally blow up – so long as it is kept dry. The researchers used a paste-like explosive material called HMX as ink in a 3D printer to create a cubical structure full of voids.

To test this holey structure, the researchers placed it between two aluminium plates and two pieces of thick plastic and added a detonator. They then poured either water, mineral oil or a salt solution into the cube or left it dry, and started a detonation. A high-speed camera recorded how the material behaved and how fast the aluminium plates moved away from it.

When the cube was dry, the plates moved slowly because the HMX combusted instead of exploding. But when the cube was filled, the detonation resulted in an explosion that pushed the plates out rapidly. From the speed of the moving plates, the researchers calculated that the explosion produced 50 times more energy than the burn (*Physical Review Letters*, doi.org/grx4rr).

Mueller says the structure’s holes changed how much energy stayed with the cube after detonation. When they were empty, lots of energy left the explosive through them. But when liquid plugged them up, more energy stayed inside the cube and that helped it build up into an explosion, he says.

According to the Small Arms Survey, unplanned explosions at munition sites cause hundreds of casualties every year. Mueller says that because the new material is barely an explosive until liquid is added to it, it is unlikely to cause similar incidents. ▮

Palaeontology

T. rex was lippy rather than toothy

Predatory dinosaurs had their terrifying teeth mostly hidden from view behind scaly lips

Michael Le Page

THE scary teeth of *Tyrannosaurus rex* and other killer dinosaurs would have been hidden by lips, contrary to film and TV depictions.

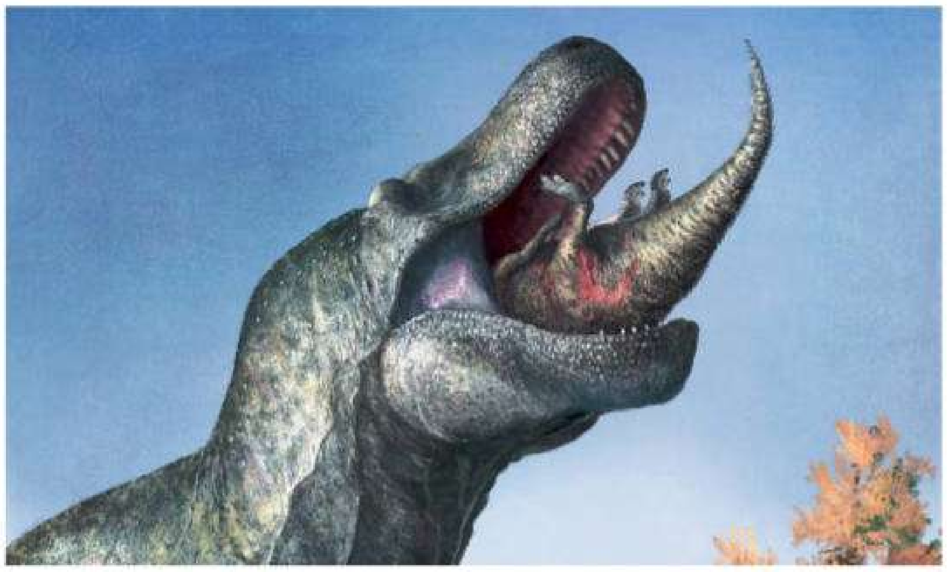
That is the conclusion of a team that has been studying the teeth of living reptiles such as alligators as well of those of ancient theropod dinosaurs, which include *Velociraptor*, *Spinosaurus* and tyrannosaurs. "We need to update what the popular idea of a dinosaur is," says Mark Witton at the University of Portsmouth, UK.

The case from Witton and his colleagues centres on tooth wear. Teeth that are always exposed should wear out more quickly than those kept inside the mouth. Physical shielding is one factor, but so, too, is the fact that enamel not kept wet by saliva dries out and gets more brittle, says Witton.

When the exposed teeth of modern alligators were examined, there was significant wear, with much of the enamel worn away. "It's like someone took sandpaper to it," says Witton.

By contrast, the team found that fossil teeth from theropod dinosaurs were in good condition, even though these dinosaurs didn't replace their teeth as often as crocodilians, an animal group that includes today's alligators and crocodiles (*Science*, DOI: 10.1126/science.abo7877). "That just isn't consistent with them being outside the mouth like a crocodile," says Witton.

The teeth are mostly hidden as this *T. rex* gulps down a young *Edmontosaurus*



MARK P. WITTON

The study also points out that many living predatory lizards have hidden teeth. For instance, the crocodile monitor lizard (*Varanus salvadorii*) has bigger teeth relative to its skull size than *T. rex*. Yet only the tips of them can be seen when its mouth is open because the teeth are covered by lips and sheathed in soft gum tissue that is pushed back by whatever it bites.

"I suspect they are right, and that tyrannosaurs had more soft tissue covering their teeth than crocodiles, but I'm still on the fence as to whether they had as much stuff covering their teeth as monitor lizards," says Steve Brusatte at the University of Edinburgh, UK.

It isn't clear if *T. rex* was more like a crocodile or a lizard, he says. "There is no good, modern-day analogue for a bus-sized superpredator with the head the size of a bathtub that crushed the bones of its prey."

Witton doubts Hollywood will make its dinosaurs less toothy. He points to film-makers being reluctant to add feathers despite evidence that many dinosaurs had them. "We're decades behind the times in terms of portraying dinosaurs in cinema," he says. ▮

Technology

AI text detection is mathematically impossible

DETECTING whether a body of text has been written by a human or an artificial intelligence model like ChatGPT is impossible to do reliably, says a mathematical proof.

The ease with which AI models generate text that seems as if it were written by a human has led to issues such as cheating on essays and disinformation campaigns. So some people have come up with methods to guard against problematic uses by embedding a hidden watermark in an AI's output or analysing the text for patterns that only an AI would produce.

Now, Soheil Feizi at the University of Maryland and his colleagues say they have mathematically proven that these techniques can't be relied on. This is because tools that paraphrase AI-generated content drastically reduce a watermark's effectiveness and because the outputs of language models will become far more mathematically similar to human speech as the models improve.

To show this, Feizi and his team used AI-based paraphrasing tools to reword AI-generated text, with and without watermarks, and fed it into several text detectors.

They found that most of the detectors' accuracy was reduced to near 50 per cent. "We see a huge drop in their performance, bringing them down to, roughly speaking, a random predictor," says Feizi.

The researchers then used a mathematical proof called an impossibility result to show that, as AI models become more human-like in the distribution of words in text they generate, detectors will struggle to cope. This means they will either identify many false positives, or not enough, letting AI text slip through the cracks. The work is posted to a preprint server, so the proof hasn't yet been peer-reviewed (arxiv.org/abs/2303.11156).

"We won't ever be able to reliably say if a text is generated by a human or an AI"

"For all practical purposes, even the best detector, that may or may not have been designed yet, won't be very good," says Feizi. "It will be basically very close to a random coin flip in terms of detecting AI-generated text or human-generated text."

"We won't ever be able to reliably say if a text is generated by a human or an AI, and I think we should learn to live with this fact," says Feizi.

Yulan He at King's College London suggests that rather than spending lots of time developing AI detectors, we should try to understand the consequences of AI generative models. "What kind of risk will they bring to our lives and how can we use them as beneficial AIs for us?" ▮

Alex Wilkins

Particle physics

Proton's size is a moveable feast

The radius of this subatomic particle seems to vary depending on how you look at it

Alex Wilkins

THE proton, one of the building blocks for all matter, is proving an awkward customer to size up. If you look at its charge, it will have one radius, but if you look at its mass, you will see a different, smaller radius.

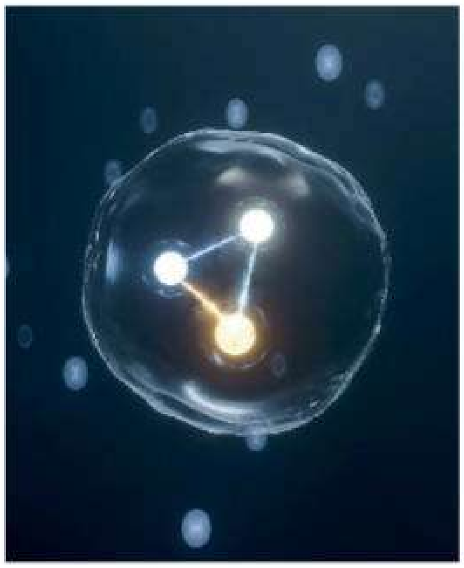
"We have a new picture of the proton. It's not that we removed information, it's new in the sense that we've added information that wasn't there," says Zein-Eddine Meziani at Argonne National Laboratory in Illinois.

In the 1960s, experiments that fired electrons at protons revealed that the latter contained point-like, electrically charged particles that we now call quarks. A proton has two up quarks and a down one. These quarks were later found to be bound together by particles called gluons.

We now know more about quarks and how far their electric field extends in space, which is sometimes called the radius of the proton. But we know less about gluons, which contain most of the mass of the proton in the form of energy, because they are chargeless, and so harder to investigate. Seeing how they are distributed can tell us about how the proton's mass is arranged and its structure.

Now, Meziani and his colleagues have probed the proton's gluons with particles called J/psi mesons. This is possible because even though gluons don't have electric charge, they have a property called colour charge, which comes from the strong nuclear force, one of the universe's four fundamental forces. J/psi mesons are made up of a charm quark and its antiquark, which also have colour charge and so are capable of interacting with gluons.

Protons contain three quarks held together by gluons


SEFA KART/ALAMY

The researchers fired a beam of photons at liquid hydrogen, which is comprised mainly of just protons, and the photons interacted with the protons. These collisions produced short-lived J/psi mesons. By measuring how many of these were produced, Meziani and his team could calculate the proton's mass distribution using quantum mechanical models that describe gluon-quark interactions.

Their results suggest that the gluons' mass is confined to a dense core in the proton's centre, while the charge from the quarks extends to a second, larger radius (*Nature*, doi.org/gr2m4j).

They also compared their results with predictions from another model of the proton, which agreed in some places and diverged at others, suggesting that the new figures need validating with more precise experiments or ones that probe proton structure in a different way, says Meziani.

"If it is confirmed, it is a very interesting finding because it tells us something quite deep about how the proton's constituents behave from a spatial point of view," says Juan Rojo at the Free University of Amsterdam in the Netherlands.

A different internal structure could have implications for calculating other proton properties, such as spin, angular momentum and energy distribution, says Rojo, which many sensitive experiments rely on. But some of the new proton findings rest on models used to calculate them, which haven't proved entirely reliable in the past, he adds.

Meziani and his team's results follow another revelation about the proton's internal structure. Last year, a team led by Rojo found that the proton can contain a much heavier charm quark, in addition to the three regular quarks. "It would be nice to see what happens if they account for a charm quark. Does the mass radius become larger or smaller?" says Rojo. ▮

Animal behaviour

Male mosquitoes may use humans as a hook-up spot

THE males of a disease-carrying mosquito species are attracted to people, even though only the females drink our blood. This suggests the males might hover around humans to pick up mates.

Researchers have previously observed male *Aedes aegypti* mosquitoes mating with females near people, but it is unclear whether the males, which feed on nectar, are attracted to people or are simply drawn towards the blood-drinking females. Female mosquitoes find people using cues such as body odour, carbon dioxide and body heat.

Véronique Paris at the University of Melbourne in Australia and her colleagues recruited 11 volunteers to stand at one end of a 3-metre-long tent, one at a time, while 100 male *A. aegypti* mosquitoes were released into the tent. Cameras were used to record where the mosquitoes were every 20 seconds for 30 minutes.

Roughly five mosquitoes circled or landed on each person, on average, at any time throughout the experiment, while no mosquitoes flew around or landed in the end of the tent without a person.

A further experiment revealed that male and female mosquitoes were preferentially attracted to the same people, although males had weaker preferences than females (bioRxiv, doi.org/j4hp).

"These insights could inform the development of new mosquito control strategies"

Learning more about the cues that attract and repel mosquitoes to people could help us improve methods for controlling mosquito populations, such as releasing sterile male mosquitoes, says Paris.

"The study provides valuable insights into the factors that influence male mosquito attraction to humans, which could inform the development of new mosquito control strategies," says Alicia Showering at the London School of Hygiene & Tropical Medicine. ▮

Carissa Wong

Environment

New way to predict river flood risk could help avoid disasters

Jason Arunn Murugesu

WE MAY now be able to better predict which rivers are at risk of extreme flooding, even if they haven't had severe floods before.

Extreme flooding is difficult to forecast, says Stefano Basso at the Norwegian Institute for Water Research in Oslo. Typically, researchers only know a river is prone to such floods if they have happened in the past.

To look for other ways to predict extreme flood risk, Basso and his colleagues analysed discharge and flooding data from 101 rivers in Germany and the US going back at least 30 years.

From this analysis, the researchers came up with two parameters that appeared to explain whether a river was likely to cause extreme flooding or not: how the area draining to the river retains and releases water, and the balance between how much rain the river receives and how much water evaporates from the region (*Nature Geoscience*, DOI: 10.1038/s41561-023-01155-w).

"Hydrologists have known for some time that the most catastrophic floods are generated by different physical processes than smaller, 'normal' floods, but the beauty of this study is that, for the first time, it identifies the places that are more likely to experience these disasters," says Paul Bates at the University of Bristol, UK. ▮

The Ahr river in Germany in 2021, when severe floods killed at least 196 people

CHRISTOPH REICHWEIN/TNN/DPA/ALAMY

Technology

Ukraine is building an AI to help triage shrapnel injuries

Matthew Sparkes

LARA HAUSER/SOPA IMAGES/SHUTTERSTOCK

Doctors in Zaporizhzhia, Ukraine, operate on a soldier hit by shrapnel

UKRAINIAN scientists are developing an artificial intelligence to help triage people with shrapnel injuries sustained during Russia's invasion, with the aid of UK researchers using 3D printing to replicate the injuries.

Kyrylo Smelyakov at the National University of Radio Electronics in Kharkiv and his colleagues are developing an AI that can analyse CT scans of shrapnel wounds. The idea is that it will work out the type of material in a wound, its location and whether there is an urgent need to remove it.

Smelyakov hopes the tool will speed up treatment at busy and understaffed hospitals across Ukraine and reveal information about wounds that might not be obvious to the naked eye.

Training such an AI system requires a lot of data, however, and a means to check the AI is accurately assessing what the foreign objects lodged inside wounds are.

Smelyakov's team has been attempting to gather this information by inserting different shrapnel materials into tissue from pig cadavers as an analogue for the human body, but the process is inaccurate and the movement of the animal tissue as it slumps and sags during CT scans reduces the quality of the data collected.

"Ideally, the AI will be able to predict with 100 per cent accuracy what the outcome is for a patient"

To improve this data collection, Smelyakov's team is taking part in the UK-Ukraine Twinning Initiative, a project that connects universities in Ukraine with others around the world to aid Ukrainian scientists as part of the war effort.

Instead of relying on pig tissue, Greg Gibbons at the University of Warwick, UK, and his colleagues are designing and 3D printing models of various human body parts.

These models will be printed from different types of plastic to replicate the densities of human tissue, then the researchers will embed pieces of shrapnel in the models and scan the whole set-up using CT scanners. The Ukrainian team will use these scans as a source of known and replicable data to train the AI.

Gibbons says his team will be exploring a range of shrapnel types, from metal of the sort that would come from a bomb or a missile to wood or glass from exploding buildings.

"Ideally, [the AI] will be able to predict with 100 per cent accuracy what the outcome is for that patient, what treatment they need, is it immediately critical, do they need it removed or can it be left in and they can be put on a ward for a while," says Gibbons. "People live with shrapnel all their life if it's not in a serious place. They don't remove it if they don't have to."

Smelyakov says his colleagues are seeing up to three new people every day with shrapnel wounds, and that the biggest problems are finding fragments less than 5 millimetres across and safely extracting bits that are close to arteries. He hopes the AI model will help.

Naeem Ramzan at the University of the West of Scotland says that, with the right training data, an AI could make a big difference in Ukraine's overburdened hospitals.

"These [types of AI model] will help to reduce treatment time and also save lives, because if you have life-threatening injuries, then it's always beneficial to have a quick response," says Ramzan. "It's actually a very viable approach nowadays." ▮

Technology

Start-up is developing world's first ammonia-powered ships

Jeremy Hsu

THE Brooklyn Navy Yard's sprawling industrial complex once employed 70,000 workers to build US battleships and aircraft carriers during the second world war. Almost 80 years later, it has become home to a New York City firm with a very different maritime mission – harnessing ammonia as a low-carbon fuel for the global shipping industry.

The start-up Amogy has already shown how ammonia-powered technology can work in a flying drone, a John Deere tractor and most recently a truck. Now, it is working on an ammonia-powered ship.

Most ships currently run on fossil fuels that emit greenhouse gases, accounting for 3 per cent of the world's carbon emissions. One alternative involves converting vehicles to hydrogen power that would only emit water. But hydrogen gas needs to be compressed and liquefied at −253°C (−423°F) for storage and transportation.

Ammonia could serve as an alternative hydrogen-bearing fuel that is more easily stored and transported in a stable liquid form at room temperature.

Hydrogen can be extracted by heating ammonia to high temperatures, which is a process that comes with its own energy cost. This is where Amogy's technology comes in. To make ammonia power more viable, the company has developed what it describes as a more efficient and miniaturised "ammonia cracking" method that can chemically extract hydrogen from ammonia at a lower temperature. It uses a proprietary catalyst to speed up the process inside a chemical reactor that feeds into a hydrogen fuel cell.

"What Amogy was able to bring to the table is that by having better catalytic technologies – what I'm assuming because this is all proprietary – they were able to miniaturise their ammonia cracking units and put them on board vehicles," says Amy Chu, a chemist at Saint Mary's College of California.

5000

Kilometres of pipeline in the US for ammonia transport

In July 2021, Amogy first showed that its system could supply 5 kilowatts of power to a drone. By comparison, a standard ammonia cracking system for extracting that amount of hydrogen power is usually the size of a large shipping container. It also paved the way for a 100-kilowatt tractor demonstration in May 2022, followed by a 300-kilowatt truck demonstration in January 2023. The firm is now working towards demonstrating a 1-megawatt system in a tugboat.

Many countries already have pipelines and port facilities for handling ammonia that is produced industrially as fertiliser for agriculture. The US alone has more than 5000 kilometres of ammonia pipelines compared with 2500 kilometres of pipeline for transporting hydrogen – though it will need more to support ammonia-powered vehicles.

Another challenge is that ammonia still "has a carbon footprint associated with the production" because the standard industrial process uses natural gas, says Ghassan Wakim at the Clean Air Task Force. Low-carbon ammonia production would require use of carbon capture.

Cleaner alternative methods could ideally use electricity from renewable power sources to split water into hydrogen for conversion to ammonia, says Wakim. ▮

Amogy is in the process of converting a tugboat to be powered by ammonia

AMOGY

Materials

Ultra-tough battery survives hammering and being run over

Alex Wilkins

A FLEXIBLE battery made from hydrogel can withstand blows from a hammer, being run over by a car and temperatures as low as −77°C (-106.6°F). It could be useful in phones or wearable electronics.

Most commercial batteries are solid and based on lithium, but can be easily damaged in accidents and cope badly in cold temperatures.

Now, Ximin He at the University of California, Los Angeles, and her colleagues have developed a hydrogel that can act as the conductive electrolyte inside a battery. In the hydrogel, long molecules are linked in a network that can hold water and is flexible and resistant to freezing.

"It could be very attractive for personal devices or flexible electronics because of this high flexibility while being highly robust," says He. "At the same time, it can work at pretty low temperatures, so our phones, for example, wouldn't die in cold weather."

To create the electrolyte hydrogel, the team mixed two liquid polymers made from the plastic polyvinyl alcohol, and slowly added zinc and potassium ions to form salt crystals to make the hydrogel conductive.

The team then sandwiched the hydrogel between a zinc anode and conductive polymer cathode to make a thin battery that might be suitable for wearable electronics. In this form, it could survive eight hammer blows or being run over by a car weighing more than 1700 kilograms, and suffered no drop in performance at -20°C (-4°F). The battery also continued to function after being cooled to −77°C and warmed up again (*Advanced Materials*, doi.org/j4pq).

However, the materials used in the new battery are expensive compared with those in existing commercial ones, which could be a barrier to its adoption. ▮

Molecular biology

Nanosyringes inject drugs into cells

Structures made by bacteria could help us deliver treatments in a more targeted way

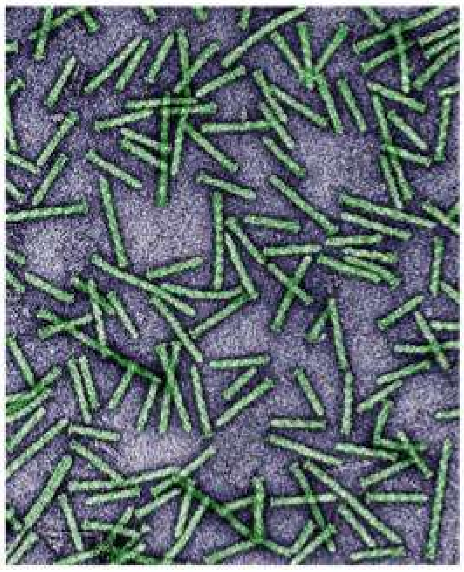
Michael Le Page

IT MIGHT become possible to inject proteins into specific cells in the body thanks to bacterial "nanosyringes" tweaked to target human cells. This could lead to safer and more effective treatments for a wide range of conditions, including cancer.

When we swallow a pill, the small molecules inside diffuse into cells from the blood. But because small molecules can enter cells easily, they aren't that specific and often have unwanted side effects.

Large molecules such as proteins can have much more specific and powerful effects than small-molecule drugs. But they can't cross a cell membrane and enter a cell, greatly limiting their uses. Effective ways of getting proteins inside cells in the body could open the door to transformative treatments for a huge range of conditions.

Many groups around the world are trying to solve this delivery issue, with only limited progress so far. But bacteria have already solved this problem. Many produce cylindrical structures that bind to cells and forcibly inject their contents into them. "They are very analogous to a syringe," says Joseph Kreitz at the Massachusetts Institute of Technology (MIT).


MIT

Nanosyringes from bacteria viewed with an electron microscope

In particular, *Photorhabdus* bacteria release nanosyringes loaded with toxic proteins when they infect insects. The nanosyringes bind to specific proteins on insect cells and inject the toxins into these cells, killing them for the bacteria to feed on.

Kreitz and his colleagues set out to adapt the *Photorhabdus* nanosyringes to target human cells. They first used the AlphaFold AI program to predict the structure of the nanosyringes, including the section that binds to protein receptors on the outside of cells and triggers the injection.

They then tweaked this section so it binds to a human protein called EGFR, which is found on the outside of some cells, again using AlphaFold to work out the effects of the tweaks. The team showed that this modified nanosyringe could deliver several different kinds of proteins of varying sizes to human cells that had the EGFR protein (*Nature*, doi.org/gr2nxw).

"The fact that this can load a diversity of different payloads of different sizes makes it unique amongst protein delivery devices," says Kreitz.

When the nanosyringes were loaded with a toxin, they killed cells that had the EGFR protein but left other cells untouched. "The targeting specificity is exquisite," says team leader Feng Zhang, also at MIT. "It's very exciting."

"The nanosyringes could be programmed to target any cell type, potentially including various cancers"

This shows that the nanosyringes could be programmed to target any cell type, he says, potentially including various cancers.

The study demonstrates that the nanosyringes work and the approach looks promising, says Amin Hajitou at Imperial College London, who has altered phage viruses to target human cancer cells. Crucially, though, the team has yet to show that the nanosyringes can deliver proteins to cells after being injected into the bloodstream. ▮

Animal behaviour

Ants farm fungus to create "cement" for sturdy nests

IN THE Americas, leafcutter ants farm the fungus that they eat, gathering bits of greenery to feed it. An ocean away, one species of ant in Africa uses a similar fungus cultivation technique. The findings suggest that this complex ant-fungus relationship has evolved independently at least twice.

From a platform suspended in the forest canopy in Cameroon, Alain Dejean at Paul Sabatier University in France and his colleagues observed tree-living cocktail ants (*Crematogaster clariventris*) making cardboard-like "carton nests" out of chewed-up plant material. The researchers cut into the nests with a machete and watched over the next few days as the ants repaired the damage with a composite material of cut vegetation and sticky pulp.

Microscopic and genetic analysis confirmed that this ant-made cement and the tough walls of the nests contained threads of the same sooty mould fungus, suggesting the ants are growing a fungus in the nest walls using harvested leaves and flowers (*Ecology and Evolution*, doi.org/j4j8).

"I don't think anyone expected to see fungus farming by ants to have evolved independently in another region," says Corrie Moreau at Cornell University in New York. "This is so shocking and exciting!"

PIOTR NASKRECKI

A cocktail ant (*Crematogaster dariventris*) cutting off a piece of leaf

The ants in Cameroon use the fungus to fortify their nests against torrential tropical rains. Even after it dies, dead fungal threads left behind in the walls strengthen the nest's construction. "If you have ever seen or touched one of these ant nests you know they are nearly impenetrable fortresses," says Moreau.

Ted Schultz at the National Museum of Natural History in Washington DC considers the report "a remarkable case of convergent evolution". He says it is likely the ants are engaging in a form of animal agriculture for structural materials, similar to human cultivation of lumber and cotton. ▮

Jake Buehler

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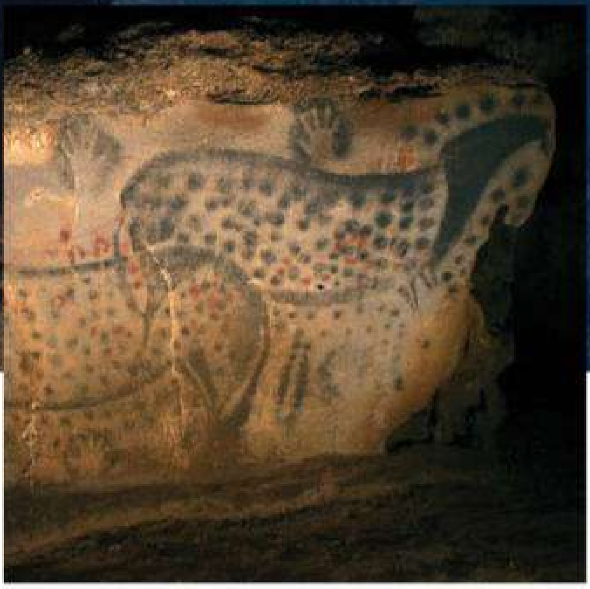

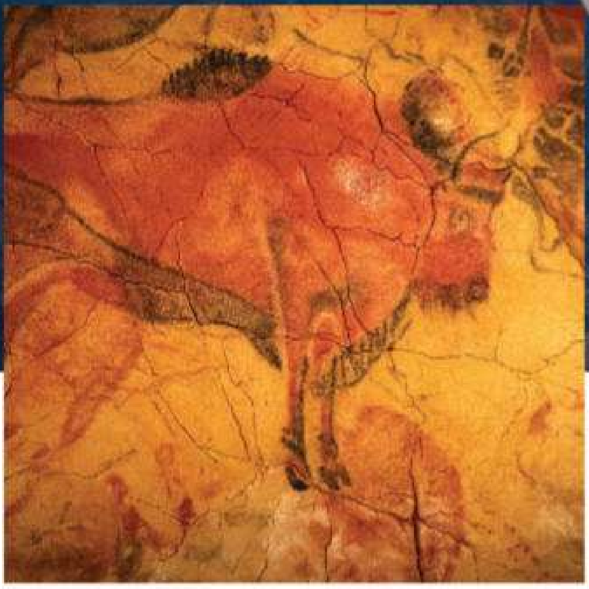

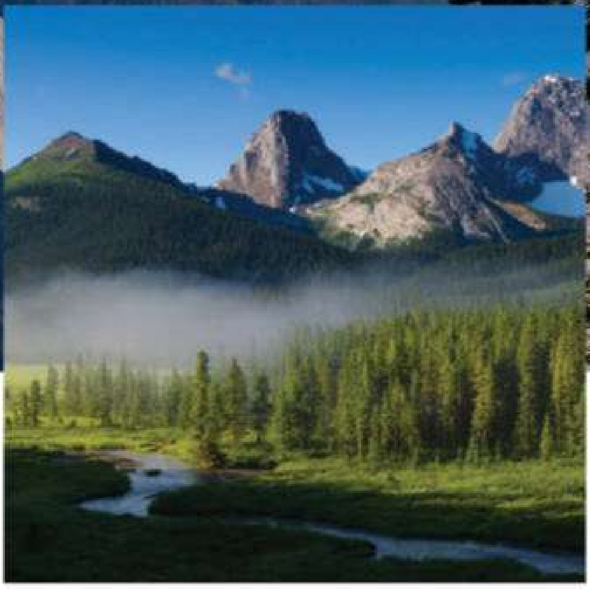

11 June | 1 September 2023 | 10 days

Neanderthal origins: Southern France

Step back in time on a journey to the key Neanderthal and Upper Palaeolithic sites of southern France between Bordeaux and Nice with Palaeolithic archaeologist and author Dr Rebecca Wragg Sykes. See some of the oldest traces left by archaic humans: stone tools, art objects, cave paintings and skeletons that have changed the way we think about Neanderthals.

In this tour, Rebecca shows how advances in archaeological methods, have transformed our understanding of these ancient ancestors. Far from confined and unvarying, Neanderthal minds were focused on quality and efficiency, yet also flexible and creative. As stone artisans, carpenters and inventors of the first synthetic material, Neanderthals pioneered new technologies, and they lived not just through ice ages but in warm woodland worlds too.

13 June | 29 August 2023 | 7 days

Ancient caves, human origins: Northern Spain

Discover some of the world's oldest known cave paintings in this idyllic part of Spain. Travel back 40,000 years to explore how our ancestors lived, played and worked.

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Accompanied by *New Scientist*'s Emily Wilson and Kate Douglas, who will give insight on the dawn of human culture and civilisation. Plus with local archaeological experts and cave custodians, you'll enjoy specialist talks and walking seminars along the way.

23 July 2023 | 7 days

The Rockies and the Badlands: Geology and dinosaurs in Canada

This tour of the majestic Rocky mountains west of Calgary and the otherworldly Badlands to the east explores the stunning scenery and geology of southern Alberta and brings to life the history of the settlements in this remote but beautiful land. You will visit two World Heritage Sites with world-class rock outcrops and outstanding dinosaur fossils. Your expert guide will tell the story of rocks and life from the Devonian period, 420-million-years-ago, to the present – a tale that includes massive reefs, dinosaur playgrounds, the formation of the Rocky mountains and, more recently, the ice sheets that carved out Alberta's spectacular landscapes.

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Ageing

Humans may not yet have hit the biological limit of our lifespan

Clare Wilson

WHILE human life expectancy has been rising for decades in most countries, the record for the longest-lived person hasn't been increasing – but that might be about to change.

Using a new way of analysing mortality records, figures from 19 high-income countries suggest that we haven't yet approached the maximum human lifespan and could see the record start to rise in the next few decades. "We don't appear to be approaching a maximum limit at the moment," says the study's lead researcher David McCarthy at the University of Georgia in Athens.

The longest-lived person in history is recorded as Jeanne Calment, who died aged 122, although there have been recent doubts about her authenticity.

Since Calment's death in 1997, the record for the oldest living person has been held by people aged between 110 and 120 – and it hasn't nudged upwards over time. This has led scientists such as Jan Vijg at the Albert Einstein College of Medicine in New York to conclude that there is probably a biological limit on the maximum human lifespan, which he puts at about 115 years old.

XINHUA/SHUTTERSTOCK

Emma Morano, one of the oldest people on record, lived to be 117

But the latest findings suggest that the maximum human lifespan will soon start rising as people born in the 1910s onwards reach very old age.

McCarthy's team came to this conclusion after studying the age at death of people in various European countries, plus the US, Canada, Australia, New Zealand and Japan. The researchers looked at the age of death in groups of people who were born in the same year. Most studies have grouped people according to their year of death, but this can obscure trends because it merges people with different lifespans, says McCarthy.

Analysing by birth year found that in those groups born after about 1910, their risk of dying in any given year increased as they aged, but to a lesser extent than those born earlier (*PLoS One*, doi.org/j4hn). This suggests that the world record for the longest-lived person will increase as surviving members of these cohorts reach advanced old age, says McCarthy.

For instance, someone born in 1910 hasn't yet had the chance to reach 120 years old.

People in these birth cohorts have benefitted from improvements in medicine since the end of the second world war, says McCarthy. We can't predict if that trend might continue from this kind of study, he says.

Vijg, however, says that the analysis depends on an assumption – that the risk of death per year starts to plateau after people reach about 105. That isn't universally accepted, he says.

But Kaare Christensen at the University of Southern Denmark says that previous studies support this assumption. "A lot of these projects hinge on models that predict what will happen in the future," he says. "The truth is nobody knows." ▮

Space

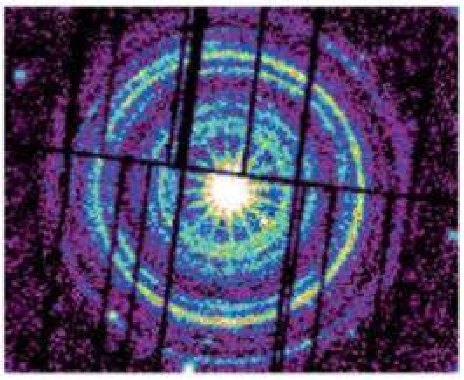
Biggest explosion ever keeps baffling astronomers

THE most powerful explosion seen may break our understanding of how cosmic cataclysms known as long gamma ray bursts (GRBs) work. The burst was first spotted in October 2022, and it is proving difficult to explain despite continued observations.

When astronomers saw the event, called GRB221009A, they dubbed it "the BOAT" – the brightest of all time. Eric Burns at Louisiana State University and his colleagues compared it with other GRBs and found that ones this bright probably only occur about once every 10,000 years, so the nickname fits (arXiv, doi.org/j4dp).

"It's probably the brightest event to hit Earth since human civilisation began," says Burns. "The energy of this thing is so extreme that if you took the entire sun and you converted all of it into pure energy, it still wouldn't match this event – there's just nothing comparable."

Other astronomers have continued to monitor the afterglow of the burst in order to determine the mechanism behind it. Most long GRBs are thought to form when the core of a star runs out of fuel and collapses, creating a black hole and stirring up the remaining stellar material into powerful jets.



ESA/XMM-NEWTON/M. RIGOSELLI (INAF)

The BOAT gamma ray burst surrounded by dust rings

But when researchers observed this GRB's afterglow in radio wavelengths, what they found didn't quite match that simple model. The energy of the jet evolved smoothly and relatively slowly over time, whereas we expect there to be fast jumps in energy as the jet develops (arXiv, doi.org/j4dr).

"When you really dig into it, all of our models are failing," says Burns. Astronomers are continuing to work to understand the BOAT, but so far it is so strange that they may have to build a new model of how GRBs work more generally. ▮

Leah Crane

Space

JWST spots earliest black hole ever seen

THE earliest known black hole in the universe has been detected by the James Webb Space Telescope (JWST).

"This is really important uncharted territory of black hole formation and growth in the early universe," says Rebecca Larson at the University of Texas at Austin.

To identify the black hole, Larson and her team pointed JWST at a galaxy that the Hubble Space Telescope had previously identified as being the brightest known galaxy in this early part of the universe.

The team dated the black hole to just 570 million years after the universe began, based on its distance from Earth (arXiv, doi.org/j4hx). Its mass is 10 million times that of the sun, making it an intermediate black hole, by cosmic standards. **Alex Wilkins**

Materials

Delicate glass items made using origami

A METHOD for shaping glass based on origami can create intricate objects that are difficult to make otherwise.

Tao Xie at Zhejiang University in China and his colleagues embedded particles of silica, the main ingredient of glass, into a sheet of a soft and rubbery polymer made of oxygen, hydrogen and carbon. They folded this sheet by hand, much like a sheet of paper, into shapes like a crane and a feather.

To transform the folded object into glass they had to destroy the polymer and fuse the silica particles together by heating it twice, first at 593°C and then at 1260°C. The resulting glass was smooth and fully transparent, says Xie. The team presented the work at a meeting of the American Chemical Society in Indianapolis. **Karmela Padavic-Callaghan**

MAURITIUS IMAGES GMBH/ALAMY

Animal behaviour

Cockroaches adapt mating strategy due to poison bait

SOME cockroaches have evolved a distaste for the glucose used in poisonous baits – and male cockroaches have adapted their mating strategy as a result.

Male cockroaches secrete a few drops of sugary fluid on their backs to entice females to mate with them. While the female mounts him and eats the "nuptial gift", the male then slips his genital hook into her, locking her into place for copulation.

However, females that are averse to glucose refuse the sugary gifts, so some males have now started secreting a new formula and hooking the females faster, says Ayako Wada-Katsumata at North Carolina State University in Raleigh.

Wada-Katsumata and her colleagues videoed 251 pairs of German cockroaches (*Blattella germanica*) in the lab. The cockroaches included some from a population that has developed glucose aversion, and another that has not.

The researchers found that glucose-averse females quickly stopped feeding on the nuptial gifts of males from the non-glucose-averse population, and they didn't mate with them. But they fed on the secretions of males from the glucose-averse population long enough for them to lock their genitals. These males were also locking into the females faster: within 2.2 seconds of the female starting to feed, as opposed to the normal range of 3.3 to 3.9 seconds.

Analyses of the secretions showed that those from the non-glucose-averse group contained five times as much glucose as those from the glucose-averse group (*Proceedings of the Royal Society B: Biological Sciences*, doi.org/gr2kbr). **Christa Lesté-Lasserre**

Really brief

IOWA STATE UNIVERSITY PRAIRIE STRIPS TEAM

Strips of native plants boost bees

Prairie strips – small areas of native plants placed in and around fields of crops – improve honeybee pollen collection. The idea has been tested in the US Midwest as part of a scheme to improve water quality and biodiversity and reduce soil erosion (*Journal of Applied Ecology*, doi.org/grx8mt).

Lizards stress eat as helicopters pass

Noise from helicopters and fighter jets over a US military base near Colorado Springs makes lizards living in the area spend more time eating, and raises their levels of the stress hormone cortisol (*Frontiers in Amphibian and Reptile Science*, DOI: 10.3389/famrs.2023.1129253).

The secret of hagfish slime

Fibrous protein threads in hagfish slime are what make it effective at clogging predators' gills, giving the hagfish time to escape. The threads spread into an intricate tangle and, in combination with mucus, transform seawater into thick goo (*Journal of the Royal Society Interface*, doi.org/j4hr).

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FRANK MARTELA

Laser light works

Certain types of light can improve the health and appearance of skin. Now scientists are finally beginning to understand how low-level laser therapy works its magic.

Natural light profoundly affects our biology, from how well we sleep, to our brain function and immune response. The ancient Egyptians used solar radiation to disinfect and heal chronic wounds and ulcers as far back as 5000 BC, making light therapy one of the oldest therapeutic methods used by humans.

Now evidence is growing that by delivering specific wavelengths of red and near-infrared laser light to precise areas of the body, it is possible to fine tune biochemical processes such as mitochondrial function and cell signalling to aid cell rejuvenation and healing.

This technique is known as photobiomodulation. It was once solely used in hospitals and clinics to reduce pain and inflammation, or promote healing of wounds, deeper tissues and nerves, as well as preventing tissue damage. However, photobiomodulation is now highly commercialised, with low-level laser therapy devices developed to allow consumers to harness its powers at home in a bid to improve the appearance of their skin.

Low-level laser therapy devices do not work like traditional ablative lasers used in the skin therapy industry. Ablative lasers create thermal micro injuries to the epidermis and heat the underlying dermis to stimulate collagen production. Instead, the new devices use laser light at much lower intensities to stimulate light sensitive molecules involved in the cascade of skin rejuvenation processes.

Laser light can penetrate further into the skin than non-coherent light because of a phenomenon known as speckle. Whenever light enters a random medium, like the skin, it is scattered and absorbed, the precise wavelength determining how far it can travel (see diagram).

But laser light has an additional property called coherence that causes it to interfere, either combining to create a bright patch or cancelling out. In skin (and other random media), this interference pattern is random—that's speckle. But crucially, where the scattered light combines to create speckle, it can penetrate deeper into the tissue at intensity thresholds sufficient to initiate biochemical cascades. By comparison, non-laser sources do not generate speckle.

"If you want to rebuild the skin, the light has to arrive at the base layer, where regeneration takes place with sufficient power," says Lucy Goff, founder of LYMA, a wellness company that has developed a low-level laser therapy device for home use.

In a study published in Aesthetic Surgery Journal, aesthetic surgeon Graeme Glass, who operates at Sidra Medicine, Qatar and is LYMA Aesthetic Director, says some experimental evidence suggests laser light is more effective in deeper target tissue but that more evidence is needed to inform clinical practice.

Various kinds of evidence has been building for some time. In 1967, Endre Mester at the Semmelweis Medical University in Hungary observed that defocused red laser light can enhance healing in mouse skin. While testing the safety of this light, he first observed an unexpected acceleration in hair regrowth, and later, enhanced wound healing. However, it has taken decades to shed more light on its reparative effects.

One challenge is understanding the mechanism behind photobiomodulation. One idea is that red laser light can trigger

"Effectively, you're supercharging the mitochondria"

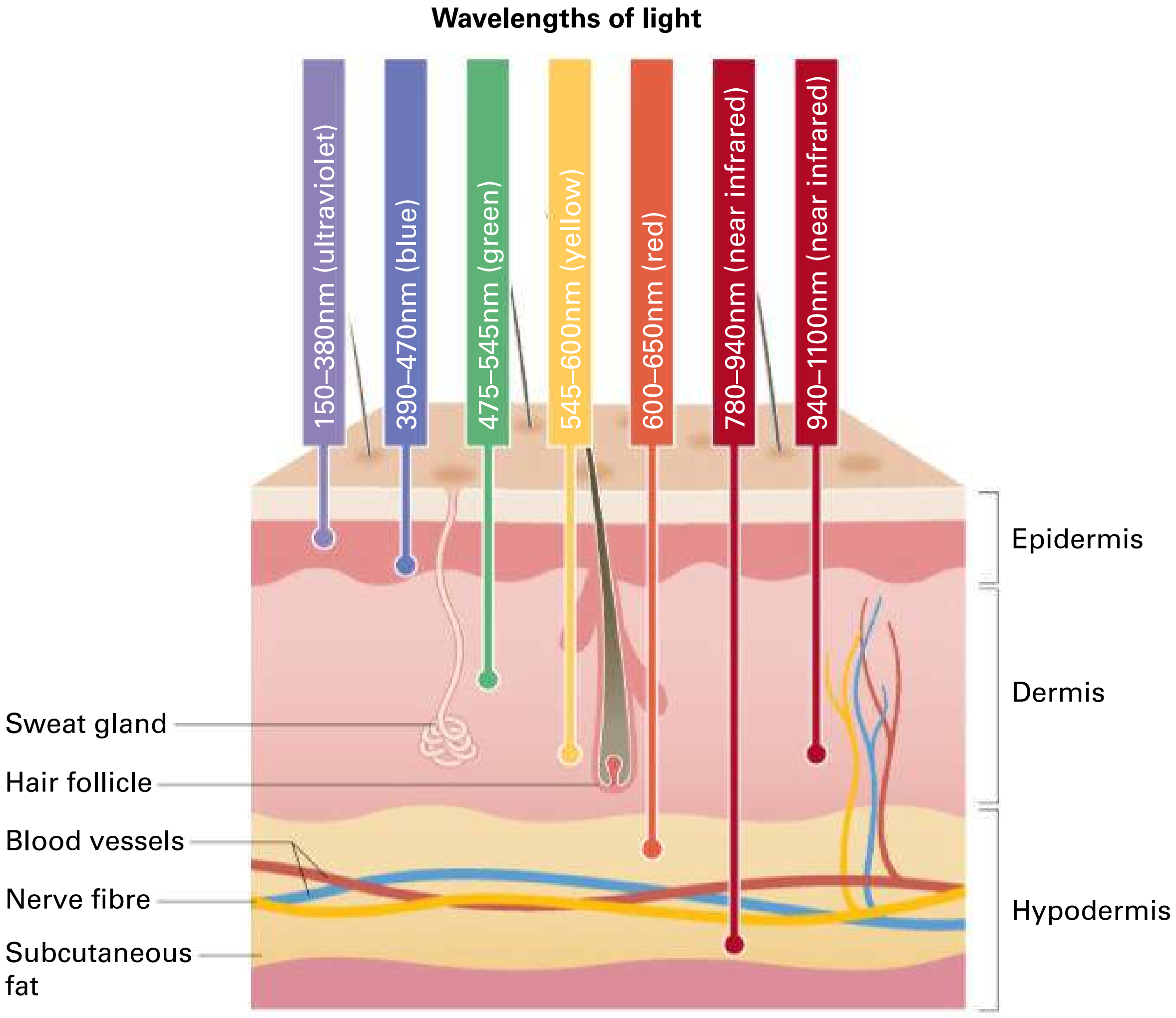
LOOPS7/ISTOCK

microscopic convection currents within cells that help mix and spread biochemical reactants and nutrients. Another possibility is that near infrared light triggers a complex cascade of events in mitochondria, the chemical factories inside a cell that generate most of its chemical energy in the form of a molecule called adenosine triphosphate or ATP. The light is thought to stimulate an enzyme involved in this cascade called cytochrome c oxidose, which accelerates synthesis of ATP. Glass explains: "Effectively, you're supercharging the mitochondria to make more ATP, which helps cell regeneration."

Photobiomodulation is also involved in wound healing. A possible mechanism here is that laser light may change the affinity of proteins called transcription factors that help turn specific genes 'on' or 'off,'. "As a result, genes that are responsible for senescence [cell death] and decline have been shown to be switched off, and genes involved in cell proliferation, survival, tissue repair, and regeneration are switched on," Glass says.

The LYMA Laser produces low -level laser light for home use

The wavelength of light determines how far into the skin it can penetrate. Laser light can travel further thanks to its ability to interfere as it scatters, creating a "speckle" pattern



There is also evidence that photobiomodulation can reduce inflammation through a separate pathway. Some trials have shown low-level laser therapy reducing inflammation in joint pain, possibly by inhibiting COX-2, an enzyme involved in inflammation and pain.

Many people opt for low-level laser therapy in the hope of preventing, or smoothing wrinkles. "As we age, we gradually lose the natural process of cell turnover," says Glass.

He believes that photobiomodulation influences skin cells called fibroblasts that produce collagen. In these cells, the cascade of events stimulated by laser light increases the gene expression for collagens and the production of polysaccharides. These sugars cause the cell to draw in water by osmosis making the skin appear firmer and more elastic.

In theory, this should reduce the appearance of wrinkles and lines and some studies appear to back this up.

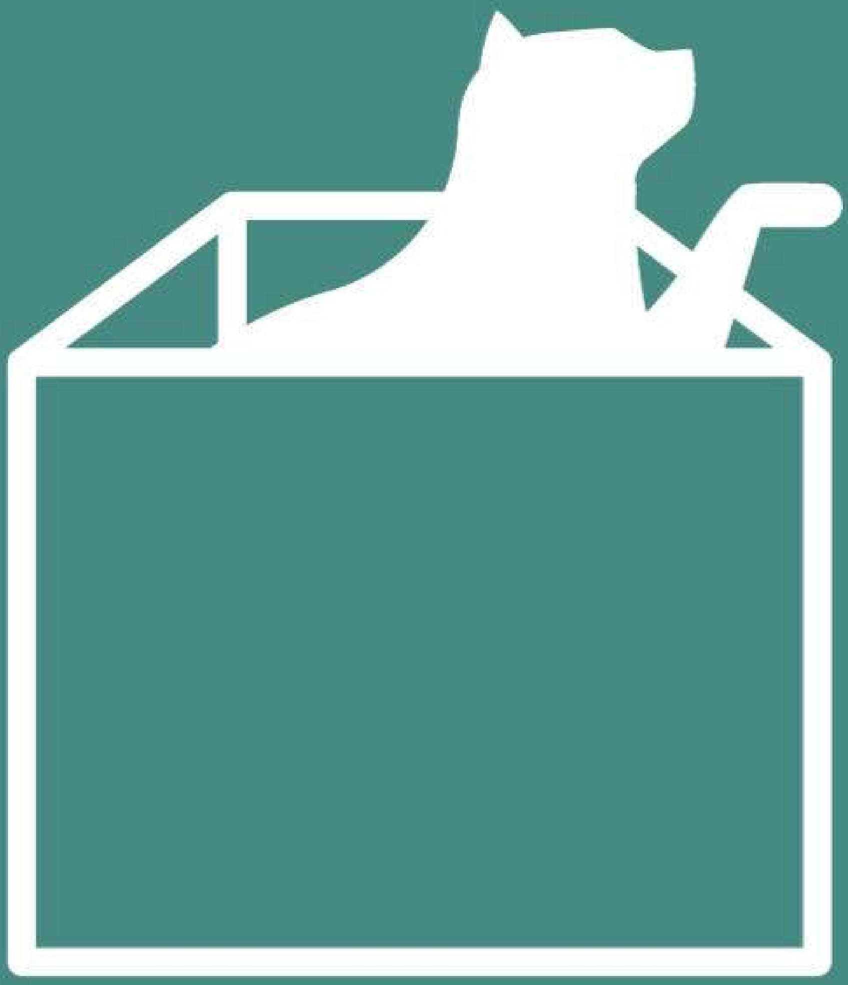
Nevertheless, more evidence is needed. After hundreds of clinical studies and decades of use, the question is not whether low-level laser therapy has biological effects, but how. In particular, researchers need to better understand the optimal parameters of these laser light sources for different uses.

That's difficult because many trials involve small patient cohorts and are often funded by industry and so are not independent. "There is ample scope to improve the quality of evidence," says Glass. He believes well-designed, adequately powered, independent clinical trials will help answer some of the unresolved questions and enable the full potential of this therapy to be realised.

In the meantime, low-level laser therapy's commercial applications are growing, with home-use laser devices, such as the LYMA Laser entering the market. Paul Clayton, LYMA director of science, recognised the opportunity to engineer a portable low-level laser therapy device with no risk of skin damage. "You can use it around your eyes to focus on crow's feet and it's perfectly safe," he says.

In short, low-level laser therapy is here to stay. "Photobiomodulation is a real phenomenon," says Glass. "The challenge is to prove its therapeutic utility in retrospect."

For more visit: lyma.life/laser



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Stand up for Earth

Comedy could really make the message about the climate crisis hit home, says **Bill McGuire** (with help from **Kiri Pritchard-McLean**)

SIMONE ROTELLA

IF YOU have taken time out to dip into the recent no-holds-barred synthesis report from the Intergovernmental Panel on Climate Change (IPCC), humour is likely to be the furthest thing from your mind. Indeed, you might think tears would be more fitting than laughter. But you would be mistaken. If campaigner Nick Oldridge and climate communications outfit Utopia Bureau have their way, we will all soon be guffawing in the face of global heating while doing our utmost to help tackle the climate emergency. (*Translated by Kiri: We're pretty doomed. Some fellas with a pretentious name are trying to help.*)

They have come up with a brilliant, if slightly left-field, idea called *Climate Science Translated*, which pairs scientists with top comedians in a series of short, hard-hitting films. Before you roll your eyes, please bear with us. At the height of a climate emergency that has the potential to bring our society and the global economy to their knees, we need every weapon in our armoury to fight global heating and its consequences, including comedy. *(Translated by Kiri: If comedians are helping scientists out, you know things aren't going well.)*

Very few outside the climate science community, (some) politicians and those who have a major stake in climate breakdown and its fallout will have read the latest IPCC report, but many millions engage with comedy. Stand-up is massive, with the big names pulling in many thousands on tour. Comics, then, are in a position to get across messages to the public in a way that most scientists will never manage, and can get away with the sort of blunt language that would make many a climate researcher blanch. It just makes sense to bring them on board. (*Translated by Kiri: Swearing is the universal language of emergencies, and we speak it.)*

The first film features me, a bog-standard climate guy, presenting the raw facts to camera. Before any viewers fall asleep, Kiri, an award-winning stand-up comic and actor, "translates" my words into a more palatable format. The second film stars atmospheric scientist Joanna Haigh, whose words are transformed by Jonathan Pie, the alter ego of actor Tom Walker.

It seems to be resonating. In just a week, the videos garnered over half a million views with no promotional budget, thanks in particular to TV presenter Chris Packham calling them "utterly brilliant". The creators are planning more in the series. After all, if a stand-up comic can't capture and hold the attention of their audience, they might as well pack up and go home. Climate can be an audience killer, but, done right, it can also change people's views. (*Translated by Kiri: I can confirm climate is an audience killer. Metaphorically and, soon, literally.*)

With comprehensive public information campaigns conspicuous by their absence, there needs to be a way of reaching those large parts of the population other messages have missed, and we think laughter is it. If leaders won't act, then it has to be down to comics to save the planet. Only comedy can translate dry science into punchy truths, can reach out to those who have never given our collapsing climate a thought and chivvy along those who are aware, but are doing little. (*Translated by Kiri: Get off the couch and into the streets if you want a non-boiling planet to live on.*)

We are facing a grim future that will become worse if we fail to act now. As a result, we are desperate for the medicine that only laughter can bring. Humour is a key part of coping during difficult times, and if we can't manage a smile even when things are going to hell in a handcart, then we really are in trouble.

Oh, by the way, have you heard the one about the climate scientist and the pork sausage? (*Translated by Kiri: I had nothing to do with that joke.*)

GUY REECE

Bill McGuire is author of *Hothouse Earth*. Kiri Pritchard-McLean is a comedian and actor

No planet B

A river runs through it The declaration of the Vjosa in Albania as Europe's first Wild River National Park is a major win. Shame about the airport planned for the river's delta, says **Graham Lawton**

Graham Lawton is a staff writer at *New Scientist* and author of *Mustn't Grumble: The surprising science of everyday ailments*. You can follow him @grahamlawton

Graham's week

What I'm reading

An advance copy of Blue Machine *by Helen Czerski, about the physics of the oceans.*

What I'm watching

I finally got round to watching the BBC's documentary about Russian opposition leader Alexei Navalny. Chilling.

What I'm working on

Rivers, rivers, rivers...

This column appears monthly. Up next week: Annalee Newitz

LAST month, I spent a few days in Albania to attend a conservation milestone, the declaration of Europe's first Wild River National Park. The river Vjosa, which rises in Greece and flows through Albania into the Adriatic, is Europe's last great free-flowing river, meaning it is uninhibited by dams or artificial banks from source to sea.

I went because I have been writing a series of articles on the shocking state of the UK's rivers. The Vjosa visit – courtesy of the outdoor clothing brand Patagonia, which has sunk the best part of a million dollars into the campaign to get it protected and has pledged $4.6 million more – was a chance to see an undeveloped river.

I wasn't disappointed, at least at first. It is an extraordinary place: wide, wild and crystalline. In its upper reaches, the river roars through stunning gorges and canyons. Lower down, it meanders and braids freely across a bed that is up to 3 kilometres wide in places, before languidly flowing into the Adriatic at a huge delta. It is also a biodiversity hotspot. Protection means that it will stay that way.

The park almost didn't happen. Albania runs on hydropower, and work began in 2007 on a hydroelectric dam on the Vjosa that would have been 43 metres at its highest point, amassing a giant reservoir behind it and trashing the river completely. The project was abandoned in 2021 after a long campaign called Save the Blue Heart of Europe, but the scars of early construction are still there.

The declaration of a river national park is a big achievement and a potential starting point for greater things in the region. Yet more remains to be done. Most of the Greek part of the river is in a national park, but a substantial section is in unprotected land. The Greek government was due to announce a decision on whether to extend the national park to plug the gap, but postponed it after the recent Tempi train crash. The current government is minded to say yes, according to Alexandra Pappa at MedINA, a non-profit organisation based in Athens, but that may not be true after the general election in May.

In addition, there are plans for a network of small hydropower plants in Greece. Four are already in operation on tributaries of the Vjosa (Aoos) in Greece, and 45 more are on the cards. If they all go ahead, it will alter the free-flowing character of the Vjosa, says Pappa.

> **"The airport is destructive enough; the infrastructure that will land in its wake will be even worse"**

But there is a bigger threat, and at the park's inauguration, Albanian prime minister Edi Rama rather soured the celebrations with it. He paid tributes all round and called the event a historic moment, but then launched into a tirade that I later learned was aimed at a conservation group, Protection and Preservation of Natural Environment in Albania (PPNEA). He spoke in Albanian, but I got the gist: the airport will be built and you can't stop it.

Rama was talking about Vlora International Airport, which is under construction on the Vjosa delta. When it opens next year, it will have capacity for 30 flights a day, eventually bringing in 3 million passengers a year, according to PPNEA. It is designed to kick-start a mass tourism industry on the coast.

I got a car to visit, and the situation was worse than I had feared. The delta is home to the Narta Lagoon, a vital habitat for flamingos, pelicans and spoonbills, and a stopover on the Adriatic flyway, a major migratory route. Its sand dunes are a breeding site for loggerhead turtles. And, to make matters worse, the runway bisects the route to the Divjakë-Karavasta National Park, another major wetland 35 kilometres to the north, which the pelicans and flamingos use to breed.

The airport is destructive enough; the infrastructure that will land in its wake will be even worse. The noise and obstruction will spook the birds and disrupt migration. Artificial lighting will threaten the turtles, which need quiet, dark beaches to breed. It isn't just nature at risk, either: plonking an airport in a place where huge pelicans fly around risks catastrophic bird strikes.

"In our view, it is inconceivable how you can have a national park all along the flow of the river, but omit the delta, which is – as every ecologist in the world will tell you – the most important part," says Aleksandër Trajçe, executive director of PPNEA.

His organisation has filed a lawsuit to stop the construction, but won't win. I understand that the campaigners had to sacrifice the delta to secure the river. I also understand the desire for development, jobs and tourist dollars in what is a low-income country. But as Rama himself said, an area designated a national park brings in 20 per cent more tourists than a similar, undesignated area. So, why risk ruining the delta?

I don't want to muddy the waters too much. The Vjosa is a major conservation win. But the delta looks like it is going to become a tragic end for an otherwise beautiful journey. ▮

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OPENING THE INFRARED TREASURE CHEST WITH THE JAMES WEBB SPACE TELESCOPE

Wednesday 17 May 2023 6-7pm BST, 1-2pm EDT and on demand

How did NASA build the JWST and what has it already revealed? Join senior project scientist for JWST and Nobel prizewinning astrophysicist John C Mather as he discusses the groundbreaking James Webb Space Telescope.

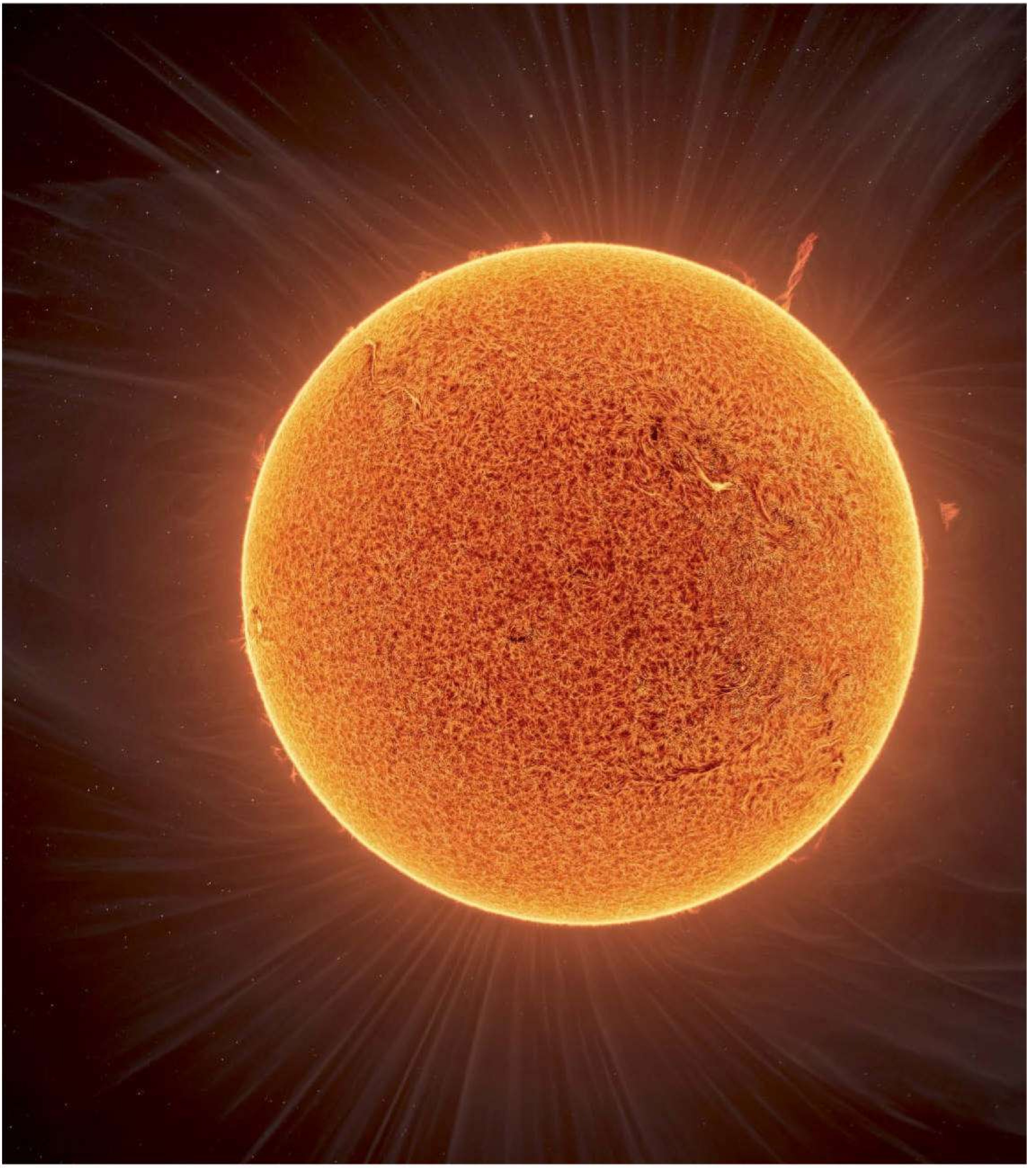
The JWST, which launched in 2021 and began science operations in 2022, is now peering into the past to find the first objects that formed after the big bang and to study the first black holes, the growth of galaxies, the formation of stars and planetary systems, and more. About 100 times more powerful than the celebrated Hubble Space Telescope, JWST could observe a bumblebee at the Earth-moon distance, in reflected sunlight and thermal emission, and it promises to reveal many wonders of our universe.

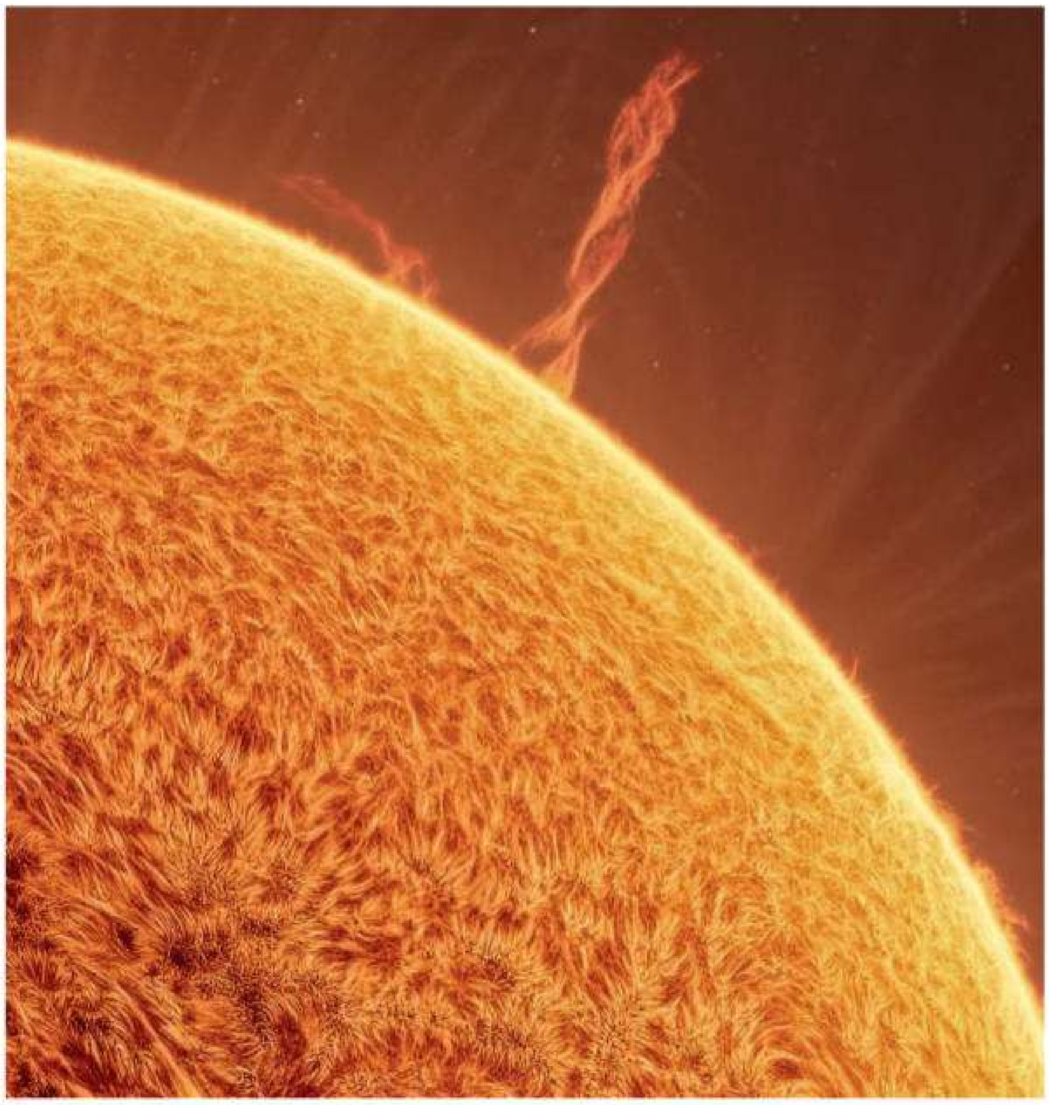
In this talk, John C Mather will discuss how NASA and its partners built JWST and share some of the telescope's first discoveries.

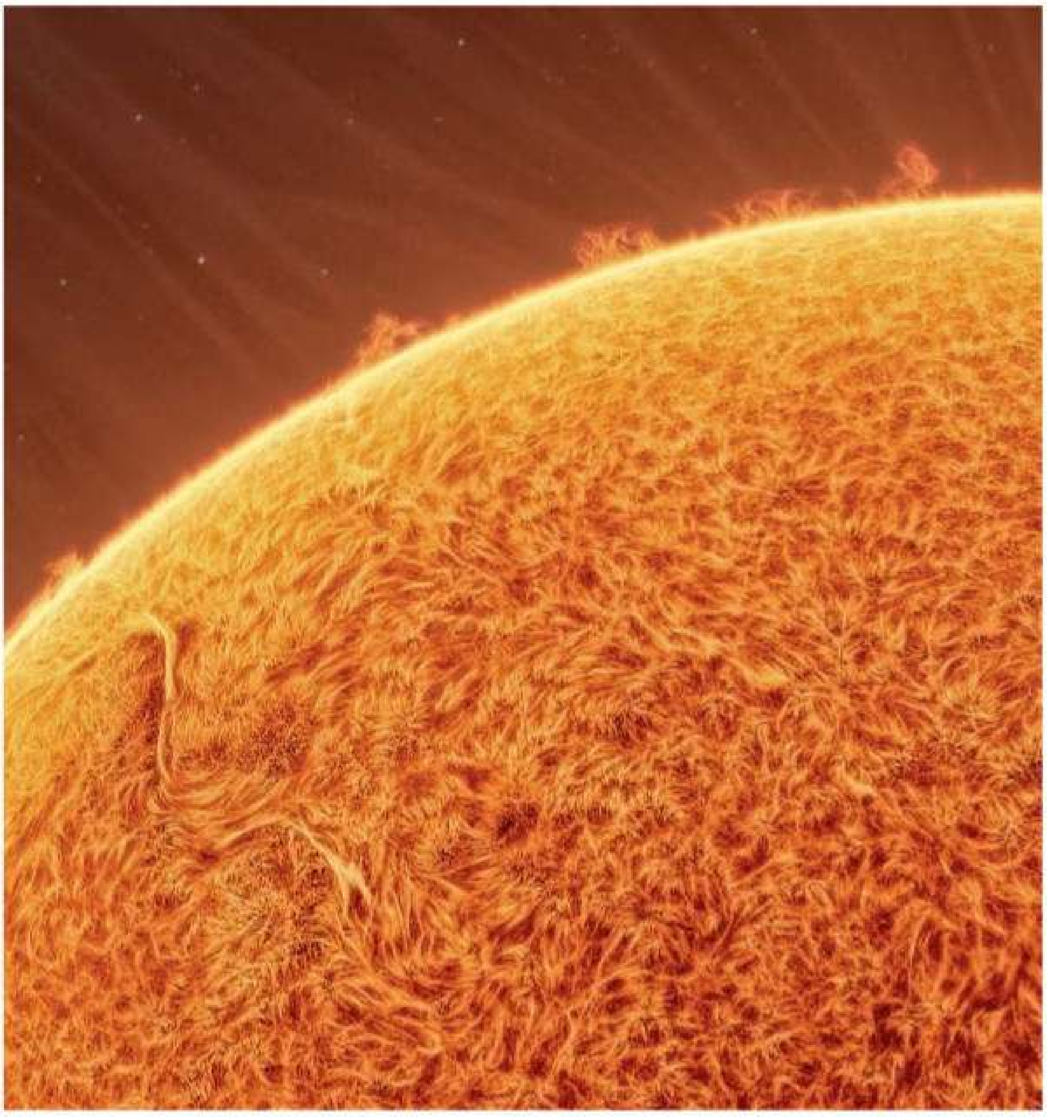
For more information and to book your place, visit **newscientist.com/space-telescope**

CHRIS GUNN/NASA

JOHN C MATHER







Solar power

Photographers Jason Guenzel and Andrew McCarthy

NEVER has the sun been seen in quite this way. This dazzlingly detailed shot of our star was recently created in the aftermath of a solar tornado of record proportions that was whipping up the sun's atmosphere. Titled *Fusion of Helios* (main image), it is the result of a painstaking five-day collaboration between astrophotographers Jason Guenzel and Andrew McCarthy, who are "always looking for fresh and creative ways to present views of the universe", says Guenzel.

On 14 March, churning plasma at the sun's surface, caused by the rotation of its magnetic fields, resulted in a "tornado" forming at its north pole. This grew into a protruding filament "14 Earths tall", according to McCarthy, or 178,000 kilometres – the tallest solar tornado ever recorded (shown top right). The blistering event lasted three days before exploding into a cloud of plasma that was ejected into space.

The pair combined more than 90,000 separate photos of the sun taken by McCarthy with a high-speed camera during this colossal event, as well as a 2017 shot by Guenzel of the sun's outer layer, or corona, visible during a total solar eclipse. Guenzel says it is the "most detailed and dynamic" image of the sun he and McCarthy have ever produced, in what was an "astounding" result. The bottom-right image is a further close-up of the main picture.

"Solar photography is an exercise in discipline, perseverance and even some luck," says Guenzel. "By combining our talents, we were able to blend art and science, creating a wonderfully unique composite view of the sun." ▮

Gege Li

Editor's pick

Surge in stomach acidity may have served a purpose

18 March, p 16

From Gautam Menon, Walsall, West Midlands, UK

The story on the possible link between emotions and gastric pH was interesting and thought-provoking. Could this be an evolutionary protective mechanism for early humans, who, being predominantly hunter-gatherers, may have been compelled to eat things that might not have been fresh in times of scarcity?

Fear, disgust or even caution may have led to a surge in acid production that could potentially destroy any significant microbial content within the meal, thereby rendering a degree of protection. We can perhaps thank our ancestors for our "gut instinct".

A calorie-controlled generation is out there

18 February, p 17

From Roy Murchie, Wivenhoe, Essex, UK

You recently ran a piece on the possible link between calorie restriction and longevity, commenting how difficult it is to run proper trials.

Has anyone looked at the UK population around the time of the second world war and soon after? Rationing provided a decent, though boring, diet for everyone. I was often peckish, but never starving. Rationing went on into the 1950s. I am 90 and I know many contemporaries who seem to be lasting well.

Let dogs be dogs and cats be cats

11 March, p 46

From Joseph Ting, Brisbane, Australia

As an admirer of both pet cats and dogs, Michael Marshall's claim that our meowing companions are "aloof and indifferent" in supplying "cupboard love" for food reeks of anthropomorphised slander, of manipulative felines yet again losing to "man's best friend". Please allow both furred companions to be themselves – that is to say, sentient beings entitled to their species' and individual natures.

Dogs and cats enhance our lives in different yet complementary ways. Dogs constantly seek affirmation and cats dispense approval when they deem such gifting deserved. Shining a light on the secondary gain basis of conditional or total devotion ruins the effervescent allure of cats and dogs. Long may their behavioural templates stay a mystery!

On the evidence for a supreme being

Letters, 18 March

From Jon Arch, Welwyn Garden City, Hertfordshire, UK

In contrast to Bryn Glover, I believe in the existence of a supreme being, despite there being no evidence from the scientific method for one. And if scientific evidence for such a being arises, I will stop believing. After all, there is a replication crisis in much of science.

From Hillary Shaw, Newport, Shropshire, UK

The science-religion debate is akin to some post-human era where intelligent rats ponder the fossil ruins of our civilisation. They attribute such objects to unknown natural processes and develop elaborate theories as to their origin. Then they discover we once existed and created such marvels as skyscrapers, cathedrals and the Hoover dam. Would the discovery that intelligent beings made such things mean it was no longer worth it for them to study the scientific and artistic principles utilised in the objects' design?

From John Hastings, Whittlesey, Cambridgeshire, UK

God would surely be clever enough to create a universe in which they can't be observed. We are well accustomed to authors of sci-fi and fantasy fiction creating worlds out of their imagination. If you asked Albus Dumbledore who J. K. Rowling was, or Gandalf who J. R. R. Tolkien was, they would not only have no information, they could argue that these authors were unnecessary. Their worlds function consistently without any need to hypothesise an author.

I conclude that the scientific method has nothing to tell us about the existence or non-existence of God.

This frozen head would surely never hop again

4 March, p 35

From Simon Goodman, Griesheim, Germany

Your review of the *Frozen Head* podcast describes a rabbit brain thawed in an "almost-perfect state", but there are caveats to that.

The brain in question was "fixed", or preserved before freezing in glutaraldehyde. This is similar to, but more potent than, the formaldehyde used in embalming fluid. Fixing means rapidly and irreversibly killing something and preserving it in a close-to-lifelike state.

The brain may have been almost perfect for microscopy, but not for other things, including living and thinking inside a rabbit head. It is beyond imagination that such tissue could be reanimated.

Want to get in touch?

Send letters to letters@newscientist.com; see terms at newscientist.com/letters

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We need a fine-grained picture on long covid

4 March, p 14

From Stephanie Woodcock, Carnon Downs, Cornwall, UK

For argument's sake, let's accept that the long covid case numbers suggested by researcher Hannah Davis and her team are reasonably correct. Their work, we are told, implies 75 million cases worldwide. If it were feasible to do so, breaking this figure down to a local level might show us a different side to long covid.

Is the picture uniform across the globe? If yes, then the 10 per cent rate of this condition in those who get covid-19 would stand as a working estimate pending long-term analysis. If, however, the answer is no and there are variations, then questions arise. For instance, perhaps the rate of long covid is significantly higher in lower-income countries where you might guess higher rates of poverty and lack of full access to care would disadvantage patients.

If it were significantly lower, this might suggest that long covid is tied to unknown factors in higher-income countries.

The race to cut emissions is becoming more urgent

Letters, 18 March

From David Flint, London, UK

Alan Walker criticises the assumptions used to estimate the additional very-long-term emissions produced by having an extra child that imply a rather large carbon footprint. That is fair enough, but we do need to drive home the necessity of urgent cuts.

The new synthesis report from the Intergovernmental Panel on Climate Change says emphatically that we have to get emissions down by 2030, then further down, then remove carbon dioxide from the air. We need a laser-like focus on these decades. What we get wrong in the next 10 years will be very hard, and perhaps impossible, to fix. ▮

AN IMPORTANT MESSAGE FROM PROFESSOR NICK LEMOINE CBE MD PHD FMEDSCI, CHAIR OF THE MEDICAL RESEARCH FOUNDATION

Gifts in Wills could be the key to protecting the future of human health

Our experience of COVID-19 shows how suddenly a global health challenge can appear. As someone interested in science, you will understand that while nobody can predict what we will face next, we can be certain that the future will bring many more threats to human health.

As Chair of the Medical Research Foundation – the charitable arm of the Medical Research Council – I have seen the incredible impact that individuals who remember the Foundation in their Wills can have on the future of our health and wellbeing here in the UK. These gifts fund research and researchers which can have far-reaching implications for human health.

With a gift in your Will you can play a key role in providing the science that will protect the health of future generations.

Right now, the Foundation is funding research to tackle antimicrobial resistance, and investing in researchers like Dr Myrsini Kaforou – who will make the fight against antimicrobial resistance her life's work.

Without support at the crucial early stages, researchers like Dr Kaforou can be forced to abandon their passion and leave science altogether, with an immeasurable loss to future human health. Gifts in Wills provide the long term funding and security that allows the Foundation to invest in projects like Dr Kaforou's and lay the foundations for quality research in years to come.

Your Will can fund the rational response to health challenges that medical science provides.

> **"As scientists, our duty is to secure the future of research for the generations that follow."**
>
> Professor Fiona Watt, Patron of the Medical Research Foundation and Director of the European Molecular Biology Organization.

Changing medicine today.
Changing lives tomorrow.
medicalresearchfoundation.org.uk

"The funding I received through the Medical Research Foundation will be transformative for my research." Dr Myrsini Kaforou

While we don't know what the future holds for human health in the UK, we do know that research, and the brilliant scientists driving that research forward, are the key to meeting those challenges for years to come.

But many of these scientists rely on the generosity and foresight of fellow members of the public – people like you, who understand the power of science and are willing to leave a gift to medical research in their Wills. At the Medical Research Foundation, over 90% of our voluntary income comes from individuals who choose to include a gift in their Will – they are crucial in the Foundation's ability to fund research that will enable the next generation of scientists to make real world discoveries in the future.

I firmly believe that a gift in your Will to the Medical Research Foundation is an excellent investment and will have a lasting impact on science and on the future of human health in the UK.

Please consider this very special gift today.

Professor Nick Lemoine CBE MD PhD FMedSci
Chair of the Medical Research Foundation

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Rooting out racism in health

A legacy of racism in Western medicine means healthcare is badly in need of decolonising. **Layal Liverpool** dissects a book that sets out why

Book

Divided

Annabel Sowemimo

Wellcome Collection

SPENCER PLATT/GETTY IMAGES

A statue of US doctor James Marion Sims was removed after protests

THERE is a paradox at the heart of Western medicine. It is built on a legacy of white doctors and scientists obsessed with skin colour, who were striving to demonstrate the inferiority of people with skin darker than theirs to justify European colonisation and transatlantic slavery. This persists today in the form of racial biases in medicine, which contribute to widely documented health disparities.

Yet Western medicine also ignores darker skin, from medical devices that don't work as well for darker-skinned patients to poor education of healthcare workers on how the symptoms of certain conditions look on a diverse range of skin tones.

Annabel Sowemimo, a writer, activist and doctor in the National Health Service in the UK, wants the ways in which past and present racism continue to shape healthcare to be recognised.

"At no point in my medical education – nearly a decade of university, three degrees and countless hours spent on the wards – did anyone mention how the legacies of colonialism and racism affect my decisions as a doctor," she writes in her book, *Divided: Racism, medicine and why we need to decolonise healthcare*.

She retells the history of Western medicine for a new generation of doctors and health workers, with a view to understanding and eliminating racism in healthcare. That history begins with the invention of race and scientific racism by European doctors and scientists at the height of colonisation and slavery.

It is an invention that affects medical practice today, from the pervasive myth that Black people's skin is thicker and therefore less sensitive to pain than that of white people, to the continued use of medical devices with embedded adjustments for measuring racially "different" lung function.

"Scientific" racism was used to perpetuate false notions of racial inferiority and superiority, with colonised and enslaved people often placed at the bottom of an imagined biological hierarchy. But, as *Divided* powerfully illustrates, many "Western" advances can be credited at least in part to the exploitation of those same people.

> **"'Scientific' racism was used to perpetuate false notions of racial inferiority"**

Take the life of James Marion Sims, long celebrated by scientific and medical institutions as the father of gynaecology. Sims honed his surgical techniques in 19th-century Montgomery, Alabama, performing painful procedures on enslaved Black women without the use of anaesthetic. His statue was removed from New York City's Central Park in 2018 following widespread protests.

Racist and colonial ideas around medical experimentation remain pervasive, as a comment made by a doctor in France towards the start of the covid-19 pandemic shows. "If I can be provocative," said Jean-Paul Mira at Cochin Hospital, Paris, during a televised discussion about the development of a covid-19 vaccine in 2020, "shouldn't we be doing this study in Africa, where there are no masks, no treatments, no resuscitation?"

Mira subsequently apologised. But, as Sowemimo reflects, his words "revealed a wound that was still festering and had been ignored for far too long: Africa and other former European colonies have historically been seen as a playground for those who wish to test their scientific hypothesis or refine their medical skills".

In addition to being used as unconsenting medical research subjects, colonised and enslaved people and their descendants have also long been exploited for their medical knowledge.

For example, the slave owner and puritan minister Cotton Mather is known for helping spread the practice of smallpox inoculation across the US and its colonies, but he learned of the idea from an enslaved Black man, renamed Onesimus by Mather. Onesimus described the practice of inoculating against smallpox, used in his country of origin, possibly modern-day Ghana. Mather is credited with promoting the idea, but the input of Onesimus isn't widely known.

Such stories are important, says Sowemimo, because they challenge the narrative that Black and Indigenous populations weren't engaging in scientific pursuits before Europeans arrived. *Divided* restores them to the history of medicine and makes a convincing case for decolonising healthcare. ▮

Layal Liverpool is a writer based in Berlin

Little marvels

We need insects more than they need us. An excellent guide to these tiny creatures reminds us why, says **Richard Smyth**

Book
Alien Worlds
Steve Nicholls
Head of Zeus

IT IS the dizzying transitions of scale that best characterise our complex relationship with insects. Zooming in, we peer with ghastly fascination at parasitoid fairy flies, which are small enough to parasitise not the bodies but the eggs of other insects. Zooming out, we gawp at the 10 million-odd insect species – and marvel that the total weight of the Amazon rainforest's ants is about four times the combined weight of all the vertebrates there.

In *Alien Worlds: How insects conquered the Earth, and why their fate will determine our future*, entomologist and film-maker Steve Nicholls handles this, and more, with great deftness in an exhilarating gallop across the hexapod cosmos.

A well-judged introduction leads us gently into chapters exploring the extraordinary lives of Lepidoptera, Hymenoptera, Coleoptera and the rest. We discover how they are constructed, what they do, how they reproduce and, here's the rub, how we would cope without them.

Not well, it seems. "The simple fact," Nicholls writes, "is that we need insects far more than they need us." Pollinators, predators, ecosystem engineers: insects of all kinds help shape and sustain the living world on which we all depend, whether we realise it or not.

Two questions are likely to preoccupy readers as they pass from the "controlled plummets" of gliding ants to the sad predilection of some Australian jewel beetles as they attempt sex with discarded beer bottles. One, why do they do what they do? Two, how do we know that they do it?

On the first point, Nicholls, like any good Darwinian, doesn't shy away from difficult questions. He walks us thoughtfully through the probable evolutionary pathways of the insect body, arthropod mouthparts, wings and flight, plant-pollinator relationships, grasshopper songs and locust swarming. Again, he demonstrates his mastery of scale and scope, skilfully evoking the depths of evolutionary time as well as the breadth of entomological diversity.

Monarch butterflies make an impressive swarm, but their numbers are falling rapidly

STEVE NICHOLLS

Yet it is on the second question where Nicholls really excels. His knowledgeable, good-humoured engagement with the human side of entomology is what elevates *Alien Worlds* above the ranks of other insect primers and handbooks.

As we might expect from his long, globetrotting career in wildlife film-making, Nicholls has a fund of his own stories – like the time he set up a colony of termites in a Borneo hotel room, only to find that his "escape-proof" polythene sheeting wasn't 100 per cent effective.

The book also illuminates the startling endeavours of other scientists and naturalists in enriching our understanding. From counting the chambers of ants' nests (the record is 7864) and measuring the running speeds of tiger beetles (one achieves a top speed of about 2.5 metres per second) to building robot dragonflies, entomology is a live science, not pinned and reeking of mothballs.

Real ecological heroes emerge, too, such as zoologist Fred Urquhart and naturalists Ken Brugger and Cathy Aguado (now Catalina Trail). They discovered the remote winter home of the endangered monarch butterfly in Mexico's Sierra Madre Occidental mountains.

Underpinning all this is the knowledge – set out starkly, but never sensationalised – that this alien world is under terrible strain. Globally, insect populations "have crashed in an alarming way", writes Nicholls. "In some places there were ten times as many insects crawling, hopping and flying about when I began my studies as there are now."

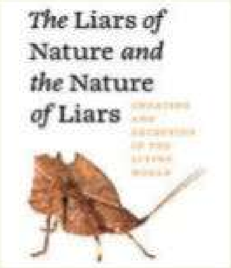
His book is an entrancing, moving exploration of the innumerable little lives flickering about us, of how they came to be here and how they may soon be lost forever. ▮

Richard Smyth is a writer based in Bradford, UK

Don't miss

Visit

Supernova Science really matters, as the destructive effects of exploding stars wreak havoc across the universe. Astrophysicist Thomas Haworth explains at the Royal Institution, London, at 7pm BST on 11 April.



Read

The Liars of Nature and the Nature of Liars are explored by behavioural scientist Lixing Sun. Cheating is found everywhere in the natural world and in human society. Interestingly, it can fuel diversity in both. On sale from 4 April.

Watch

Stories of Paper Innovation are told by Nasreen Khan at Georgia Tech, as she probes paper's past (like printing with wood blocks, above) and its future. Online at 7pm EDT on 11 April and then on demand.

ROBERT C WILLIAMS MUSEUM OF PAPERMAKING; NASA/JPL-CALTECH

The games column

A walk in the woods

The Forest Cathedral is a video game adaptation of Rachel Carson's *Silent Spring*, a book that helped create an environmental movement and transform the world. Can it live up to its pedigree? **Jacob Aron** explores

Jacob Aron is *New Scientist*'s news editor. Follow him on Twitter @jjaron

Game

The Forest Cathedral

Wakefield Interactive

PC and Xbox Series S/X

Jacob also recommends…

Games

Firewatch

Campo Santo

PC, PlayStation 4, Xbox One, Nintendo Switch

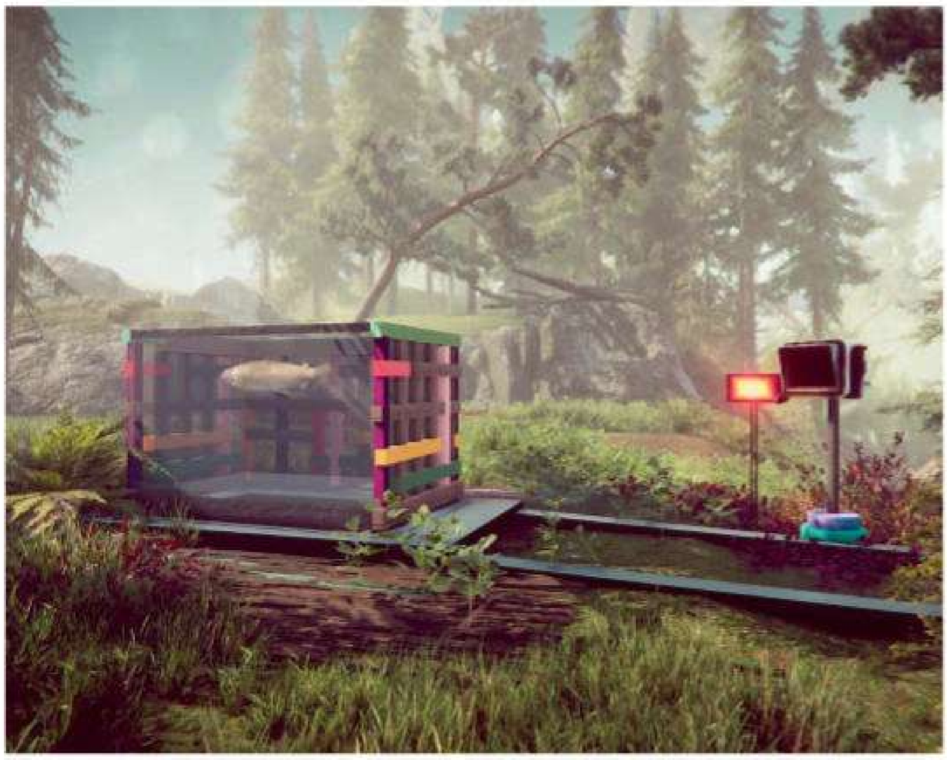
You play as a fire watcher in Wyoming, exploring the nearby landscape to solve problems and uncover a mystery. Utterly gorgeous.

The Witness

Thekla Inc

PC, PlayStation 4, Xbox One, Android

Navigate an island full of puzzles to unlock a secret at its core. A masterpiece of design, it is full of moments that lead to sudden realisations and stretch your mental capabilities.



WHITETHORN GAMES

Monitors on the island let you play a 2D video game-within-the-game

THE opening of *The Forest Cathedral* is one of the most arresting I have seen in a video game. Unfortunately, it all goes downhill from there.

When I first came across this game, an adaptation of *Silent Spring*, Rachel Carson's massively influential book, it seemed to have been designed with *New Scientist* readers in mind. Carson was a biologist and conservationist who discovered that the pesticide DDT, intended to kill mosquitoes and other disease-spreading insects, could harm animals higher up the food chain. Her exposure of the problem helped spark an ecological movement that led to the creation of the US Environmental Protection Agency.

Such video game adaptations of books are rare, and of non-fiction ones even rarer, so I was intrigued to see how *The Forest Cathedral* would work. The answer is, it doesn't.

Let me back up. The game opens with you controlling a ladybird flying through a forest, as both menacing music and an ominous whooshing sound grow in volume, until the ladybird lands on a branch and dies in a fog of DDT. You then briefly play as the person spraying this chemical, until eventually Carson is introduced. She is hired by Paul Hermann Müller, the real-life discoverer of DDT's insecticidal properties, to study an island where it is being used. This is entirely fictional; the two never met. The dialogue is oddly stilted, almost like something out of a David Lynch movie, but it is hard to know if this is an artistic choice.

> "The game does a good job of explaining how Rachel Carson realised the pesticide DDT could harm other animals"

At this point, we are introduced to the Little Man, one of the most bizarre elements of the game. Despite it being set in the early 1960s, when a single computer could still fill an entire room, all of the equipment on the island is computer-controlled and you manipulate it by manoeuvring a small figure, the Little Man, through a 2D *Super Mario*-esque video game-within-the-game that is played on monitors dotted around the forest.

At this point I should admit that I haven't actually read *Silent Spring*, but I can hazard a guess that it didn't involve Carson playing what may be one of the worst platforming games ever created. The Little Man is horrible to control, all the levels are incredibly frustrating and I spent every single minute cursing his existence. I can only think that developer Wakefield Interactive felt the need to put more "game" in its game, since your time as Carson is mostly spent walking from A to B, but it is a serious mistake. *The Forest Cathedral* only takes about an hour to play, but it felt much, much longer.

In the game's favour, it does do a good job of explaining how Carson realised that small amounts of DDT in the lower echelons of the food chain could bioaccumulate, reaching larger doses in predators like rainbow trout or eagles, both of which we see die in the game, and potentially threaten people. You don't experience this via game mechanics, however, making me wonder what the point of adapting the book was.

To be fair to Wakefield, it is clear this is a game made by a small team on an even smaller budget, and, given that, there is only so much that could have been done.

To that end, I applaud the ambition in adapting *Silent Spring*, and would certainly like to see more developers looking to books for inspiration, but it is hard to recommend that anyone actually play *The Forest Cathedral*. ▮

Where will the arms race end?

As tensions rise,
is Putin thinking the unthinkable?

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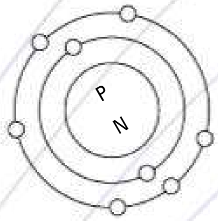
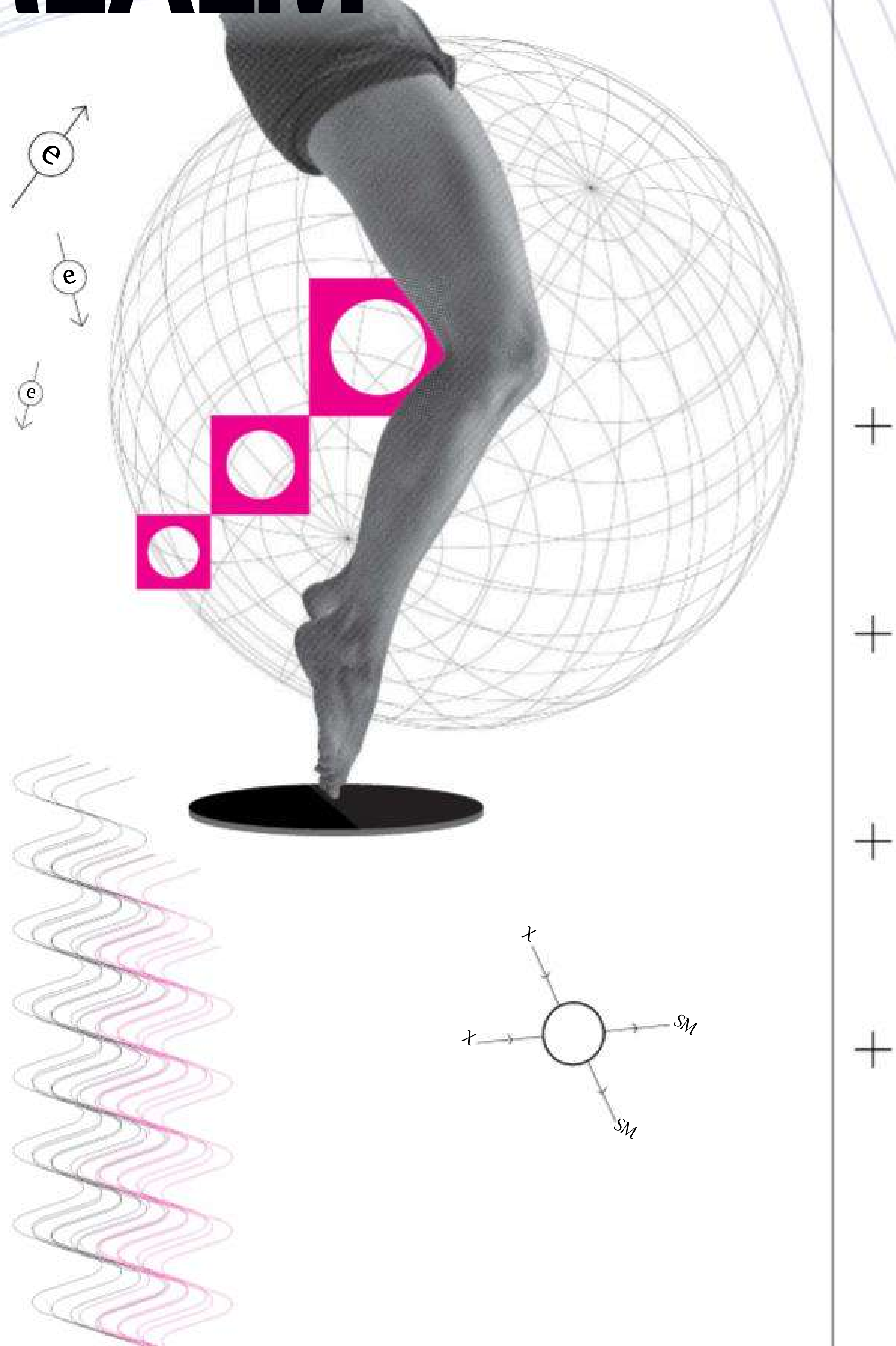
AN INVENTORY OF THE QUANTUM REALM

The ancient Greeks speculated that it might be air, fire or water. A century ago, physicists felt sure it was the atom. Today, we believe that the deepest layer of reality is populated by a diverse cast of elementary particles, all governed by quantum theory.

From this invisible, infinitesimal realm, everything we see and experience emerges. It is a world full of wonder, yet it can be mystifying in its weirdness. Over the next 10 pages, **Jon Cartwright** presents a guide to its inhabitants and their strange behaviours – as well as some of the hypothetical particles that physicists still hope to discover





RYAN WILLS

MATTER

We start with what we pretty much know for sure. Visible matter consists of atoms, and at the centre of atoms are protons and neutrons. But even these aren't elementary particles, as detailed by the current "standard model" of particle physics, our leading description of reality on the tiniest scales. So we begin, deep down, with what matter is really made of.

ELECTRONS

Weighing in around 1800 times lighter than protons or neutrons, electrons add very little to the overall mass of atoms. Without the electron, however, we would scarcely be able to feel matter at all. That is because electrons have a negative charge and exist in an "orbit", or cloud, surrounding atomic nuclei. When you touch something, the atoms in your fingertip aren't directly butting up against the ones in an object. Instead, what you are feeling is the mutual repulsion between the negative electrons surrounding the atomic nuclei in your finger and those in the object, via the force of electromagnetism (see "Photons: Electromagnetism", page 39).

The electron plays the lead role in almost all other aspects of everyday life, too. By and large, when atoms bind in solids, liquids and gases, it is through the transfer or sharing of electrons, to balance charge and make things stable. All chemical reactions – from photosynthesis to combustion, from decomposition to the subtle reactions involved in our sense of taste and smell – similarly boil down to electron rearrangement. They are also the vehicles of electricity: their fine manipulation in transistors, which control the flow of electrical current, is what makes computers and many other modern technologies possible.

QUARKS (UP AND DOWN)

"Three quarks for Muster Mark!" heckles a character in *Finnegans Wake*, James Joyce's famously indecipherable novel. Joyce apparently intended "quark" to mean the caw of a crow. For physicist Murray Gell-Mann, however, the term was suitably bizarre to describe the elementary particles he successfully predicted in the 1960s and that combine to constitute protons and neutrons.

Here, quarks come in two types, up and down – but don't take these labels literally. The difference is that the up quark has a fractional charge (that is, a fraction of the electron's charge) of $+\frac{2}{3}$, as opposed to the down quark's $-\frac{1}{3}$, and is less massive. The neutron contains two down quarks and an up; the proton, two up quarks and a down, all stuck together with another type of elementary particle – the gluon (see "Gluons: The strong force, page 39"). Do the maths and you see that this is why the proton is slightly lighter than the neutron and has an overall positive charge. It is this that ropes negative electrons into orbits around atomic nuclei.

NEUTRINOS

In the standard model of particle physics, electrons and neutrinos are classed as leptons, a word derived from the Greek for "small". And while the electron's mass is small relative to that of protons, neutrons and quarks, it is a beast compared with the neutrino's, which is believed to be a million times less. What's more, being electrically neutral and therefore heedless of the electromagnetic force, the neutrino is the wispiest of matter particles, zipping through objects almost completely undetected. Did you notice that, while reading this, billions of neutrinos – produced via nuclear fusion in the sun – were coursing through your eyeballs? Us neither.

Still, neutrinos do interact with matter very occasionally, via the weak force (see "W & Z bosons: The weak force", page 40) that is involved in various types of nuclear decay. But we don't always see what we expect in these ›

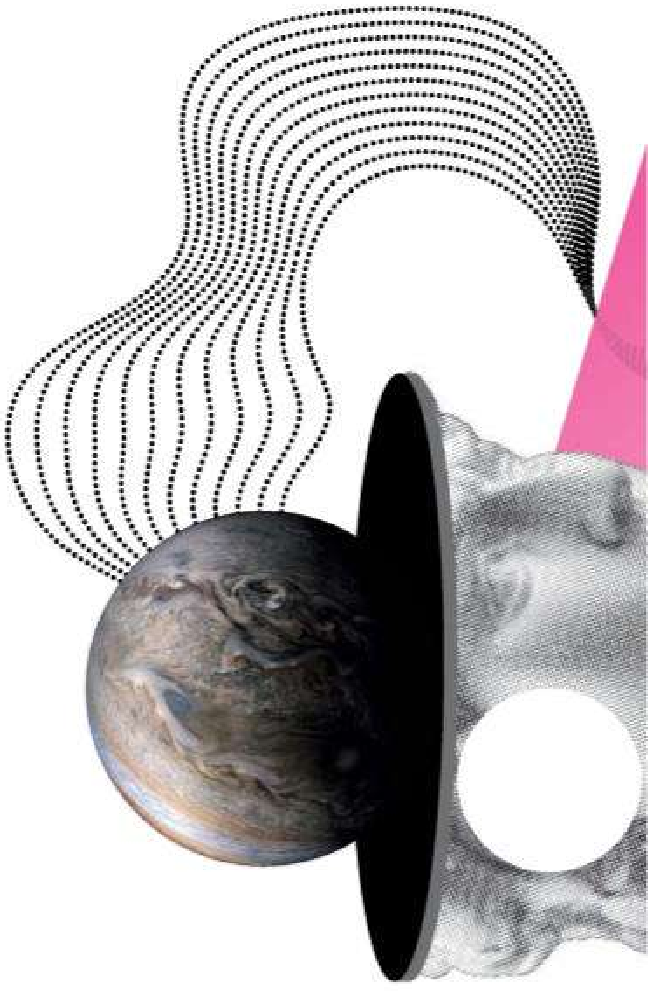
Question
IS REALITY MADE OF PARTICLES OR FIELDS?

We talk of particles, which is to say things that occupy points (more or less) in space – yet particles are just energetic spikes, or "excitations", in underlying quantum fields. A photon, say, as the carrier of electromagnetism, is an excitation of the underlying electromagnetic field.

These fields permeate the entire universe, which means that there is some residual photon-ness everywhere – so-called virtual particles, which appear fleetingly and then vanish – even when there isn't enough energy around to manifest a particle proper.

Fields, then, are usually considered more fundamental. The maths simply doesn't work without them. But the ambivalent quantum nature of a field means that it can't be observed directly: any observation requires a dose of energy that, in effect, forces the field to show its hand and produce a particle. For this reason, particle talk seems unavoidable. Particles are what we see.

events. That is because quantum laws allow neutrinos to oscillate between different flavours: an "electron neutrino" can transform into a "muon neutrino" or a "tau neutrino". In this way, neutrinos are a window into the strange fact that matter comes in what particle physicists refer to as three generations.



OTHER QUARKS AND LEPTONS

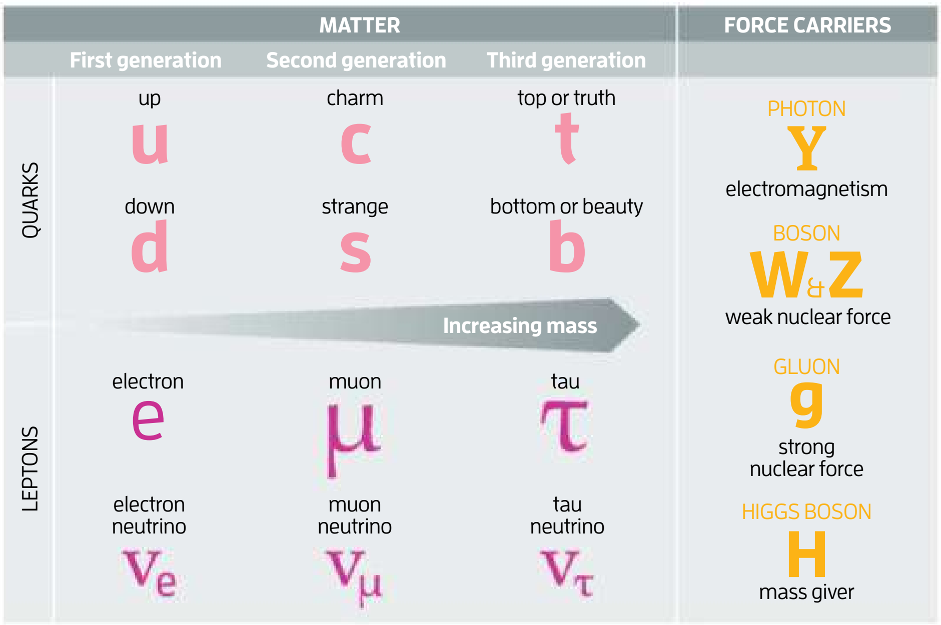
For each of the four original, or "first-generation", elementary matter particles, physicists have also found not one, but two duplicates, differing only from the originals in their greater mass. For the up quark, the heavier duplicates are the charm quark and top quark; for the down quark, there is the strange quark and bottom quark; for the electron, we have the muon and tau; and for the electron neutrino, the muon neutrino and tau neutrino.

"Who ordered that?" asked Nobel physics laureate Isidor Rabi when the muon was discovered in 1936. Physicists haven't lost his incredulity. Some of these second and third-generation particles are heavy indeed – the top quark dwarfs even the mighty Higgs boson (see page 40) – yet, as far as we know, they are identical to their forebears in all other respects. No one knows why they exist. In fact, they don't seem to have a very active role in the universe at all.

What we can say is that they make things more complicated. With a total of six different quarks, for instance, nature is known to permit more than 150 composite particles, in addition to the familiar proton and neutron. We have discovered many two and three-quark composites and are now finding four and five-quark ones. All of which might sound like nothing more than stamp collecting. But the hope is that small variations in the rates of the events producing these composite particles will explain why nature seems to prefer matter over antimatter (see "Where has all the antimatter gone?", right).

The standard model

Despite missing a few pieces, the collection of particles we have identified provides a remarkably accurate picture of all visible matter and three of the four fundamental forces



	MATTER			FORCE CARRIERS
	First generation	Second generation	Third generation	
QUARKS	up u	charm c	top or truth t	PHOTON γ electromagnetism
	down d	strange s	bottom or beauty b	BOSON W&Z weak nuclear force
LEPTONS	electron e	muon μ	tau τ	GLUON g strong nuclear force
	electron neutrino ν_e	muon neutrino ν_μ	tau neutrino ν_τ	HIGGS BOSON H mass giver

Increasing mass

Strange behaviours

A selection of the phenomena that earned the quantum world its reputation for weirdness

WAVE-PARTICLE DUALITY

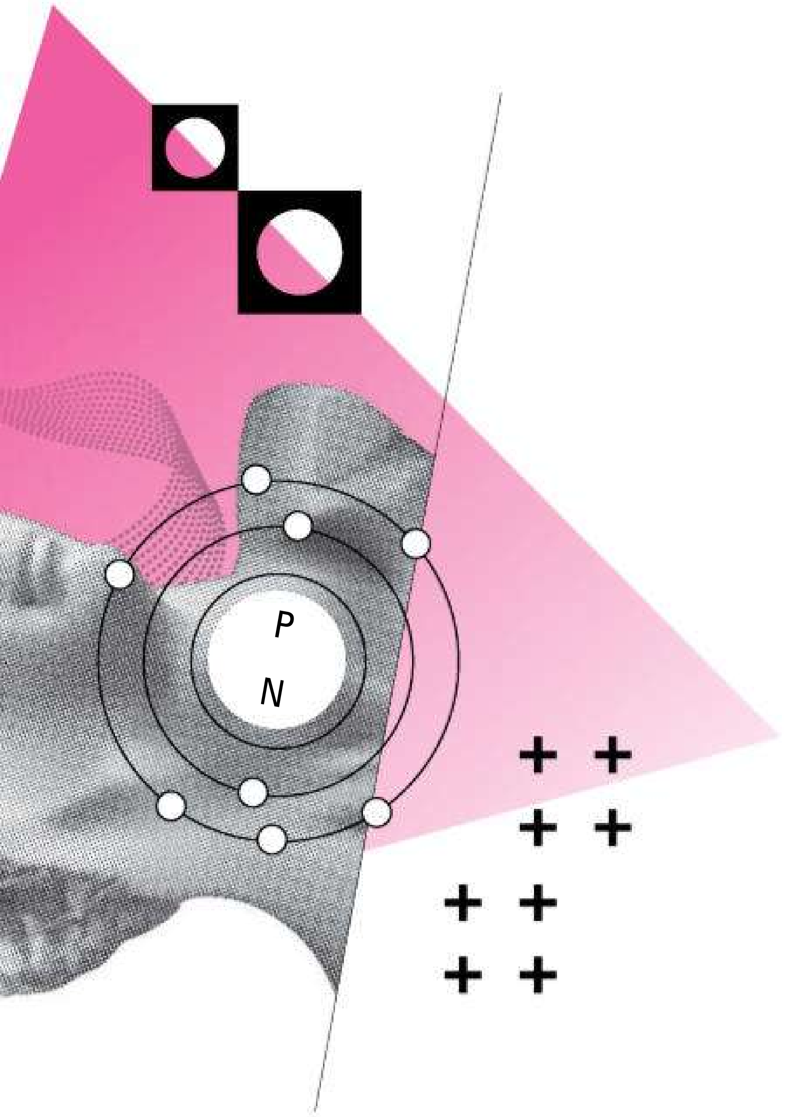
The double-slit experiment is among the most elegant in the history of science. It involves firing a stream of single particles – electrons, say – at two narrow slits that are close together. A measuring device behind the slits records a pattern of light and dark stripes, as though the electrons passing through the different slits act as waves that diffract and interfere with one another, like water ripples from two stones dropped on a still lake. The pattern emerges even if the electrons are fired one at a time, suggesting that a single electron can traverse both slits at once – again, like some sort of spread-out wave.

That isn't the strangest part. Put detectors at the slits to work out which slit each electron goes through and you will find that it now chooses one or the other – and the interference pattern vanishes. The electron seems to behave like a particle when you check, but a wave otherwise.

SUPERPOSITION

It is often said that particles can be in two places at once, but that isn't quite true. What is really going on is that a quantum object exists in a superposition of states, a circumstance in which a particle is simultaneously in all possible positions, say, until it is measured. At that point, a mathematical entity known as the wave function, which encodes all possible outcomes of the measurement, collapses. Suddenly, the particle has definite properties that we would describe as real (see "Who or what collapses the wave function?", page 43).

It is, then, more accurate to say that particles *seem* to be in two places at once – and the distinction is important. A superposition is a mathematical way to make sense of what we observe, such as particles also behaving like waves. We don't observe superpositions themselves. Whether or not they are real depends on whether you think the maths is itself reality or just a tool we use to describe it.



FORCES

Matter would be incomparably boring on its own: forces make the universe tick. But our modern understanding of force is nothing like the classical notion of one lump of stuff exerting itself on another. Instead, we know that there are four fundamental forces and that they themselves consist of particles that are being constantly emitted and absorbed by matter.

Quantum laws

A selection of the rules and principles that govern the subatomic realm

QUANTISATION

In 1900, physicist Max Planck was trying to make sense of the mathematics that governs the energy output of light bulbs. He took a punt that, rather than emitting energy continuously, a radiating body releases it in packets, or "quanta". Soon after, Albert Einstein proposed that all light is made of indivisible, particle-like quanta, which became known as photons. In due course, physicists came round to the idea that everything comes in discrete packets: energy, momentum and, of course, particles themselves. The possible exception is the force of gravity, but most physicists today suspect that even this will eventually prove to be quantisable and written in the laws of quantum physics (see "Gravitons", page 41).

Question

WHERE HAS ALL THE ANTIMATTER GONE?

Pretty much every particle we know has a doppelgänger, or antiparticle. These have the same mass as their standard counterparts and they, too, fall in a gravitational field. The difference is that they have opposite charge – oh, and that there are vanishingly few of them around. Antimatter is generated by us in particle collisions, but the visible universe is overwhelmingly made of matter, not its opposite. And no one knows why.

If they were simple opposites, matter and antimatter would have been produced in equal amounts by the big bang and annihilated one another shortly afterwards. Yet nature, it seems, prefers matter.

Most physicists believe the explanation for this is that the laws of physics aren't perfectly symmetrical. Perhaps a slight asymmetry means that normal matter always gains the upper hand. Experiments have detected a certain amount of this "symmetry violation", but not yet enough to explain the full extent of matter's dominance.

PHOTONS: ELECTROMAGNETISM

The electron, a matter particle of everyday physics, works in partnership with the carrier of the electromagnetic force, the photon. When two electrons repel each other, they recoil in opposite directions as one of them emits a photon and the other absorbs it (see "How forces work", page 41). The arrangement of atomic electrons gives materials their colour, but it is the absorption and re-emission of photons by a material that conveys its colour to the retinas of our eyes. Photons also make the rearrangement of electrons in chemical reactions possible, by putting energy in or taking it away.

Sometimes, we see these photons as visible light, such as the flame produced in a combustion reaction. More often, we don't. A flame also produces photons in the form of heat (infrared radiation). These are invisible because their energy is too low for our eyes to detect. Photons that are even less energetic make up radio waves, while very high-energy photons constitute the equally invisible but dangerous ultraviolet rays, X-rays and gamma radiation.

GLUONS: THE STRONG FORCE

The strong nuclear force, which holds together quarks inside protons and neutrons, is delivered by the gluon – no prizes for guessing where that gets its name. Gluons operate through something that is unique to quarks, known as colour, a special quantum property that has nothing to do with colour as we know it. Quarks and gluons come in three colours, red, green and blue, which mix to make white. In an interaction, a gluon can change the colour of a quark, but if it does, another gluon will change the colour of a neighbouring quark, so that white remains their overall mix. For instance, a proton's three quarks might at one moment be red, blue and green; at another, they might be green, blue and red. No one said particle physics was simple.

Gluons have such a strong grip that quarks are never observed in isolation. This also means gluons harbour a lot of energy, which translates, via Einstein's mass–energy equivalence, to a lot of mass. In fact, the vast majority of the mass of the atom comes not from quarks and electrons, but from gluons.

Strange behaviours and quantum laws

ENTANGLEMENT

If you and your friend received a series of dice in the post over several days and you flipped them at the same time each day, you wouldn't expect the results to correlate with one another. The outcomes would be unrelated. Yet if you could repeat this with pairs of entangled electrons, that is precisely what would happen. Every time you receive an electron that is spin-up – spin being a quantum property akin to angular momentum – your friend would find that their electron is spin-down, and vice versa. That is because when two such particles are brought together in a certain way and then separated, measurements on one instantaneously seem to influence the outcome of measurements on the other – even though there is no conceivable way the pair could communicate.

Einstein disparagingly called this "spooky action at a distance", because information can't travel faster than light. But entanglement, otherwise known as non-locality, has since been demonstrated in countless experiments. It has not only transformed how physicists think about reality, but it also forms the basis for all manner of quantum technologies, from cryptography and information teleportation to quantum computing.

THE EXCLUSION PRINCIPLE

Most people probably think they know what matter is. In fact, a common-sense definition isn't obvious. Take an apple. Most of its matter consists of quarks, but no one has ever seen, felt or tasted a quark. Any sense you have of the apple in some way involves – between you and the apple – an unthinkably complex exchange of the lightest elementary matter particles, namely electrons, and massless force carriers, namely photons.

Matter and force are inextricably linked. Even so, one trait does distinguish matter: it takes up space. Due to a fundamental asymmetry in the maths describing matter particles, no two can slot into the same quantum state. Known as the exclusion principle, this phenomenon prevents electrons that surround atomic nuclei from overlapping in the same orbit, which, in turn, prevents atomic collapse, and gives rise to the volume of objects.

W & Z BOSONS: THE WEAK FORCE

The carriers of the weak nuclear force, which governs some types of radioactive decay, are friendly giants. Unlike the photon and gluon, which are massless and travel at light speed, the W and Z bosons are slow and could tip the scales even against atoms of iron. Yet, compared with the photon and gluon, the effect that the W and Z bosons have on other particles is hundreds of billions of times feebler. That is because, in quantum physics terms, mass doesn't equate to strength, but reach, or rather lack of it: the weak force has a range of less than a quadrillionth of a millimetre (10^{-15}mm).

Still, they can have powerful consequences. In the fusion of hydrogen into helium in the sun, one of the up quarks in the hydrogen's proton changes into a down quark, transforming that proton into a neutron – a necessary step as, unlike hydrogen, helium requires neutrons as well as protons. To make this happen, the former proton's positive charge must be carried away with the emission of a W+ particle. In this way, the humble W boson keeps the sun shining – and makes life on Earth, and you, possible.

THE HIGGS BOSON

Mass isn't an easy concept. We tend to equate it with weight, but that is really a measure of gravitational attraction, even though the terms weight and mass are often used interchangeably. A proper definition of mass relates to inertia, in the sense of how much an object resists acceleration when a given force is applied to it. A bicycle has a certain inertial mass; a 50-car freight train, much more so.

Named after theorist Peter Higgs, one of the people who predicted its existence, the Higgs field is what gives particles inertial mass. Neither force nor matter, the Higgs field is unique among quantum fields in having a finite intensity at all points in space, even in a vacuum when there isn't enough energy for its particle manifestation, the Higgs boson, to be present. The matter particles, as well as the W and Z bosons of the weak interaction, are effectively bogged down by the Higgs field to varying degrees, thereby acquiring inertial mass. Otherwise, they would be massless and move, like photons and gluons, at the speed of light.

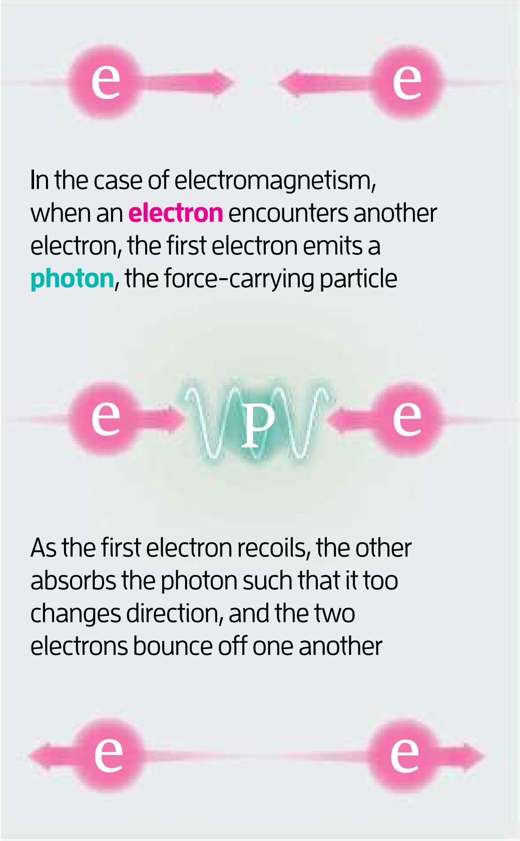
> "IF THE HIGGS WERE JUST A BIT MORE MASSIVE, THE UNIVERSE WOULD BE A BLAND PLACE"

Many questions surround the Higgs. Can it interact with itself, to acquire its own mass? Is there just one type of Higgs or are there more, perhaps ones that constitute dark matter, the mysterious stuff that keeps galaxies from flying apart? Maybe the biggest mystery, though, concerns the measured value of the Higgs boson mass and the intensity of the underlying field. At 125 gigaelectronvolts, it is hefty – equivalent to the mass of over 100 protons or that of a moderately sized molecule – yet also seemingly precisely tuned to make life possible. If it were just a few times more massive, atomic nuclei would be unbalanced, hydrogen would be the only stable element and the universe would be very bland.

Worse still, according to theoretical calculations, the Higgs field isn't necessarily in its most favourable state. At any moment, it could slip into a more stable configuration that isn't just a few, but billions of times more intense, instantly turning our orderly universe into chaos. This would be a purely random event, based on a phenomenon known as quantum-mechanical tunnelling, in which a particle can surmount an energy barrier that appears insurmountable. Fortunately, such an event is predicted to occur just once every googol (10^{100}) years or so.

How forces work

Deep down, forces operate via the exchange of force-carrying particles.



In the case of electromagnetism, when an **electron** encounters another electron, the first electron emits a **photon**, the force-carrying particle

As the first electron recoils, the other absorbs the photon such that it too changes direction, and the two electrons bounce off one another

UNDISCOVERED MARVELS

The list of known particles comes to about 30, depending on how you count them. But now we must enter the unknown – the thicket of hypothetical particles that have been proposed to solve the things we don't yet fully understand, from gravity and the big bang to the mysterious presences of dark matter and dark energy.

GRAVITONS

Gravity itself isn't in question: it is the fourth fundamental force and the only one to have achieved household-name status. But its force carrier, the graviton, remains hypothetical. That is partly because no one is sure that gravity can be quantised (see "Quantisation", page 39) and partly because, even if it can, its quantum particle would be incredibly difficult to detect.

This is because gravity is so excruciatingly weak. Earth produces a gravitational field strong enough to keep our feet on the ground most of the time, yet even children can momentarily escape its pull every time they jump. The field would have to be a whole lot stronger to manifest a single graviton. How strong? Well, physicists have imagined placing a graviton detector with the mass of Jupiter in orbit around a neutron star, which are notoriously dense and, as such, perhaps the biggest single sources of gravity besides black holes. They predicted that the detector could record one graviton every 10 years. If the detector was 100 per cent efficient. Maybe.

INFLATONS

The universe we observe is surprisingly uniform. On the grandest scales, one patch of sky looks much like another: a continuous pattern of stars and galaxies, almost as though they evened themselves out during the expansion from the big bang. But that is impossible, according to Einstein's special theory of relativity, as it would › require information to travel faster than light.

Maybe the universe we see is merely a speck of a primordial super-universe, a speck that, for a brief moment, inflated much faster than the general expansion. Rather like blowing up a single pixel from a digital image, our cosmos was filled with a space that was comparably bland and featureless. In this idea, this cosmic inflation was driven by a particle known as the inflaton, which has some of the same characteristics as the Higgs boson. In fact, some theorists think the Higgs could be the inflaton, although it would have had to behave very differently in the early universe.

QUINTESSENCE

We have come a long way since the "steady state" theory, popular until the middle of the 20th century, which held that space is essentially unchanging. All observations suggest that there was once a big bang and that space has been expanding ever since. Many physicists believe there was an early burst of particularly rapid expansion called cosmic inflation. Now, it seems that the expansion of space is again accelerating, though far more slowly than in the early universe, due to some mysterious entity known only as dark energy.

Dark energy has a strong claim to being the most mysterious thing out there. No one knows what it is and physicists are struggling to figure out precisely how it behaves, given that its effects take place over billions of years. Still, there are a few candidates. One is that, in addition to the four known fundamental forces, there is a fifth force, or "quintessence". The related particle doesn't have a name. What we do know is that, by necessity, the quintessence must be weaker than gravity, so it is difficult see how we would ever detect one of its particles.

Quantum laws

RANDOMNESS

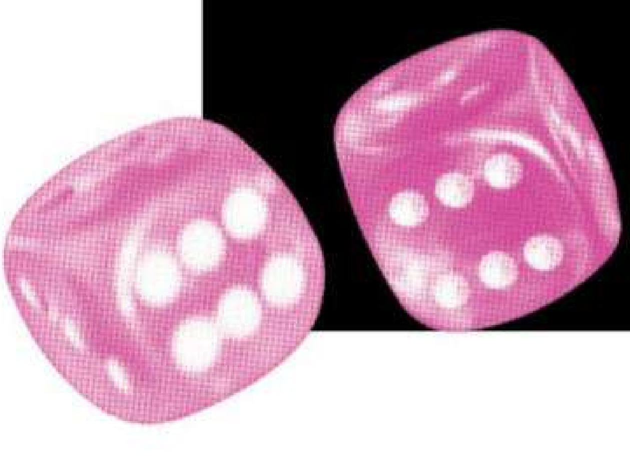
Sooner or later, most particles decay. Indeed, it is through analysis of what they decay into that new ones are discovered. But particles don't decay in the same gradual way as, for example, a tree stump or that bit of cheese lurking at the back of your fridge. For instance, a free neutron could be 1 minute or 100 years old and still have the same likelihood of decaying into a proton, an electron and a neutrino. True, the average lifetime of a neutron is 15 minutes, but, at any single moment, the chances of decay for one neutron are precisely the same as any other, no matter their age. If and when it happens, it is sudden and unpredictable.

Einstein had no truck with this randomness, famously inistsing that God doesn't play dice with the universe. Yet, time and again, experiments have indicated that quantum processes aren't deterministic, but inherently random.

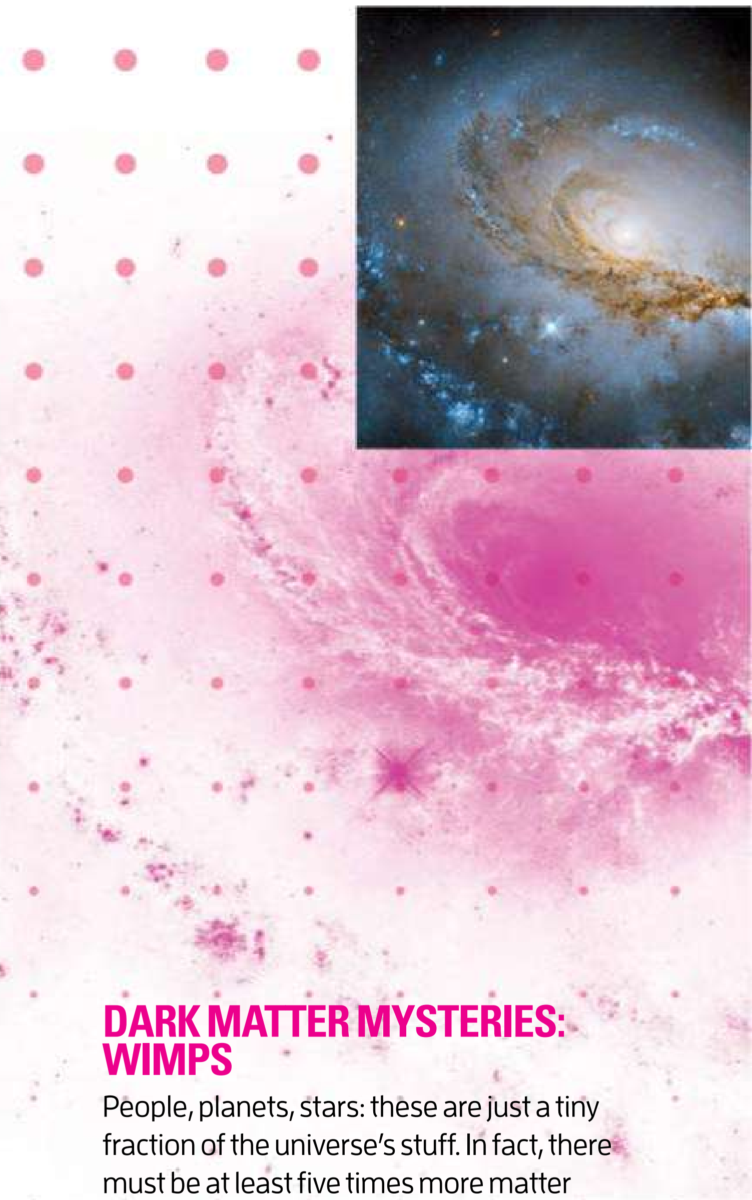
UNCERTAINTY PRINCIPLE

The quantum world doesn't play by common-sense rules. After all, in the right circumstances, a particle can readily behave like a wave. But even the notion of a particle itself gets fuzzy under scrutiny. Try to locate a particle and suddenly its momentum – the way it is moving through space – becomes obscure. Try to record the particle's momentum, on the other hand, and you lose any sense of where it actually is. This is the quantum uncertainty principle, identified by Werner Heisenberg in the mid-1920s.

It would be reassuring to think that this uncertainty is just an artefact of our imperfect measurement devices. The more established view, however, is that the properties themselves are hazy concepts. In which case, what we naively refer to as a particle is a chimera, and what is truly "there" is something beyond our common notions of place and movement, space and time.



GAIL SHOTLANDER/GETTY IMAGES



DARK MATTER MYSTERIES: WIMPS

People, planets, stars: these are just a tiny fraction of the universe's stuff. In fact, there must be at least five times more matter than we can see, otherwise galaxies wouldn't generate enough gravity to stop themselves flying apart. The extra stuff is called dark matter, but what exactly is it?

Dark matter is invisible, in the sense that it doesn't absorb or reflect light. Yet we can infer a few things about its properties. It must interact with visible matter only weakly, otherwise we would have detected it already. And it probably consists of massive particles – up to 10 times that of the Higgs – otherwise it would be created too easily in today's universe and make things unstable. Weakly interacting massive particles, or WIMPs, seem to tick all of the boxes. These have long been the favoured dark matter candidates, but despite the odd teasing hint, they have never been discovered.

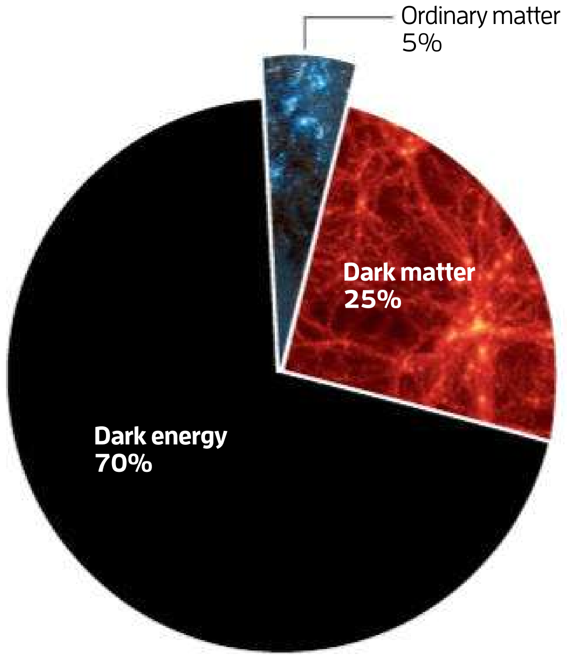
AXIONS

Perhaps dark matter isn't made up of matter particles at all, but force carriers. If so, the particles could be so weakly interacting that, unlike WIMPs, they form a stable population in today's universe whatever their mass. Based on these criteria, the bookies' favourite is the axion. Named after a brand of washing detergent, the axion was originally introduced to "clean up" a different problem: why the strong force affects quarks and antiquarks in precisely the same way, when the basic theory permits wild discrimination.

NASA, ESA, J. DALCANTON, R. FOLEY

Shadow stuff

Visible matter makes up a small fraction of the overall energy content of the universe, the rest being dark matter and dark energy



The axion field would enforce equilibrium in the strong force, like a finger on the balance. If the particle solves dark matter too, all the better.

STERILE NEUTRINOS

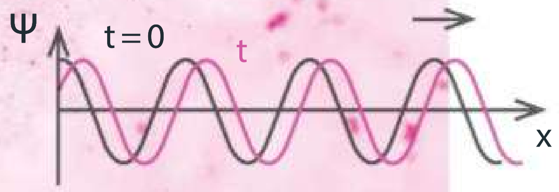
Arguably the simplest candidate for dark matter is one that does nothing but boost the gravity of galaxies and other large structures. Unlike its known counterparts – the electron, muon and tau neutrinos – the sterile neutrino would be indifferent, or "sterile", to the weak force. It would interact via gravity, and gravity alone, quietly yet firmly keeping galaxies intact. A preponderance of sterile neutrinos could easily be dark matter, then, and maybe solve some other problems. Their fields could mix with those of the known neutrinos, explaining why these have a very small but finite mass. And because sterile neutrinos would decay to produce more matter than antimatter, they could explain why our universe is dominated by matter (see "Where has all the antimatter gone?", page 39).

Question

WHO OR WHAT COLLAPSES THE WAVE FUNCTION?

One of the most startling features of quantum physics is the scantness of properties needed to define a particle: essentially all you need is its mass, charge and angular momentum, or "spin". Knowing these, it is possible to solve a mathematical equation and end up with a term that describes the particle in full – literally, everything that can possibly be known about it. This is the wave function, and it tells you the probability of the particle behaving in a certain way at any particular moment. It is closely tied to the phenomena of wave-particle duality and superposition: left to its own devices, a particle exists in a placid, wave-like range of possible states, but once observed, its wave function "collapses" and the particle adopts a specific state, occupying a localised place in time.

But who, or what, is actually needed to do the observing for this to happen? Will a detector do, or does a person need to watch over it? Quantum physicists are haunted by their inability to say for sure and have come up with myriad interpretations. Perhaps human consciousness is necessary. Or perhaps wave function collapse doesn't happen at all, but only appears to – perhaps all possible states still exist in bifurcating parallel universes, the so-called many worlds interpretation of quantum theory. There is no easy answer.



DARK PHOTONS

What if the dark universe is as complex as our own? Could there be dark stars? Dark planets? Dark civilisations? There is no evidence for any of this, but it is still tempting to think that dark matter isn't just some idle blob. Perhaps, like visible matter, it has at least one force of nature it can call its own. Enter the dark force and its carrier: the dark photon. This would make dark matter particles interact with one another, in a closed community. Should it exist, the consequences of a dark photon are tantalising, given the incredible diversity of phenomena for which the normal photon is responsible. It could bind dark matter particles into atoms, for instance, or form the basis of a dark chemistry.

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FINAL FANTASIES

There are at least four fundamental forces, but why four? In fact, physicists hope that they will turn out to be facets of one single, unified force – a universal set of equations that describe the behaviour of everything in the universe. Success depends on reconciling the two greatest physical theories of the 20th century: quantum theory and Einstein's theory of gravity. Time to venture into the deepest unknown.

> "TWISTOR THEORY SAYS PARTICLES ARE JUST THE GLOSS OF A DEEPER REALITY"

Question

WHAT IS A THEORY OF EVERYTHING?

There is good reason to think that the differences in the fundamental forces are only superficial. For a long time, electricity and magnetism were considered separate forces, until physicist James Clerk Maxwell showed in the 1860s that they are really two aspects of a single phenomenon: electromagnetism. Then, from the 1950s, electromagnetism and the weak force came to be seen as a single phenomenon, albeit united only at energies found in nature 1 billionth of a second after the big bang. Out of the maths of this "electroweak" force pops the Higgs boson.

Calculations suggest that at even greater energies – those present even closer to the big bang – the strengths of the electroweak force and the strong force are identical. That is why theorists suspect that these, too, can be married as a single force, described by a grand unified theory. Most of these churn out so-called supersymmetric particles (see "Sparticles", left).

What about gravity? The fourth force is much harder to embrace in quantum theory because it is bound up with space-time, the very stage on which particles go about their business. For this reason, "theories of everything" that include gravity usually posit that particles are facades for entities that are more elementary and mind-bending, such as strings or loops.

X BOSONS AND LEPTOQUARKS

Combining the electromagnetic and weak forces provided the theoretical basis from which we predicted the existence of the Higgs boson (see "What is a theory of everything?", right), so it follows that incorporating the strong force will also entail new particles. One of the possibilities for such a "grand unified theory" is that quarks, governed by the strong force, can convert into electrons, neutrinos and other leptons governed by the electromagnetic and weak forces. Such conversions would have to be mediated by new force-carrying particles, known as X bosons and leptoquarks.

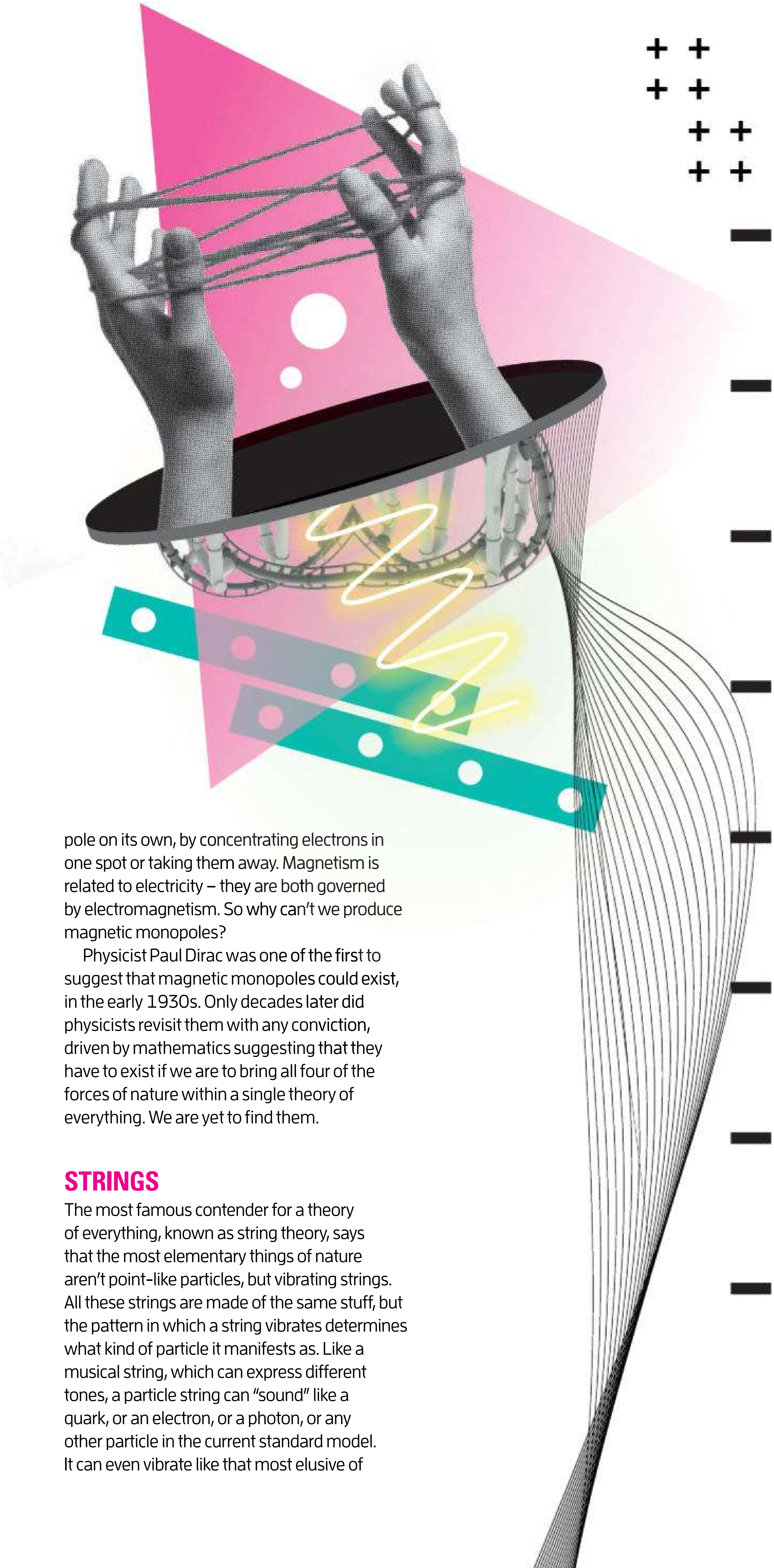
SPARTICLES

In particle physics terms, matter and force are different only in as much as matter particles take up space, whereas force particles don't (see "The exclusion principle", page 40). For decades, however, physicists have entertained a deeper, "supersymmetric" theory that makes matter and force two sides of the same coin. It holds that every known matter particle has a corresponding, heavier force particle, and vice versa, designated by an "s" prefix or "ino" suffix. The force partner of a quark is a heavy "squark", for instance, while the matter partner of a gluon is a heavy "gluino", and so on.

Supersymmetry has long been invoked as a potential grand unified theory. It also provides a neat way of explaining why the Higgs boson is much, much lighter than theoretical predictions would otherwise imply: the extra, heavy particles balance the equations. The problem is that the world's biggest particle smasher, the Large Hadron Collider at CERN near Geneva, has found no evidence of supersymmetry.

MAGNETIC MONOPOLES

Every magnet has two poles: north and south. Which is strange, when you think about it. Electrical terminals also often come in pairs – positive and negative – yet it is possible to create a single negative or positive electric



pole on its own, by concentrating electrons in one spot or taking them away. Magnetism is related to electricity – they are both governed by electromagnetism. So why can't we produce magnetic monopoles?

Physicist Paul Dirac was one of the first to suggest that magnetic monopoles could exist, in the early 1930s. Only decades later did physicists revisit them with any conviction, driven by mathematics suggesting that they have to exist if we are to bring all four of the forces of nature within a single theory of everything. We are yet to find them.

STRINGS

The most famous contender for a theory of everything, known as string theory, says that the most elementary things of nature aren't point-like particles, but vibrating strings. All these strings are made of the same stuff, but the pattern in which a string vibrates determines what kind of particle it manifests as. Like a musical string, which can express different tones, a particle string can "sound" like a quark, or an electron, or a photon, or any other particle in the current standard model. It can even vibrate like that most elusive of force carriers, the graviton (see "Gravitons", page 41). The catch is that strings need to vibrate in 11 dimensions.

Proponents say this isn't as fantastical as it sounds, as the extra dimensions might be curled up around the strings so tightly as to be beyond our abilities to detect. Still, string theory has taken a knocking in recent years because it acts as a master theory for supersymmetry and its multitudinous offspring, none of which have been found.

LOOPS

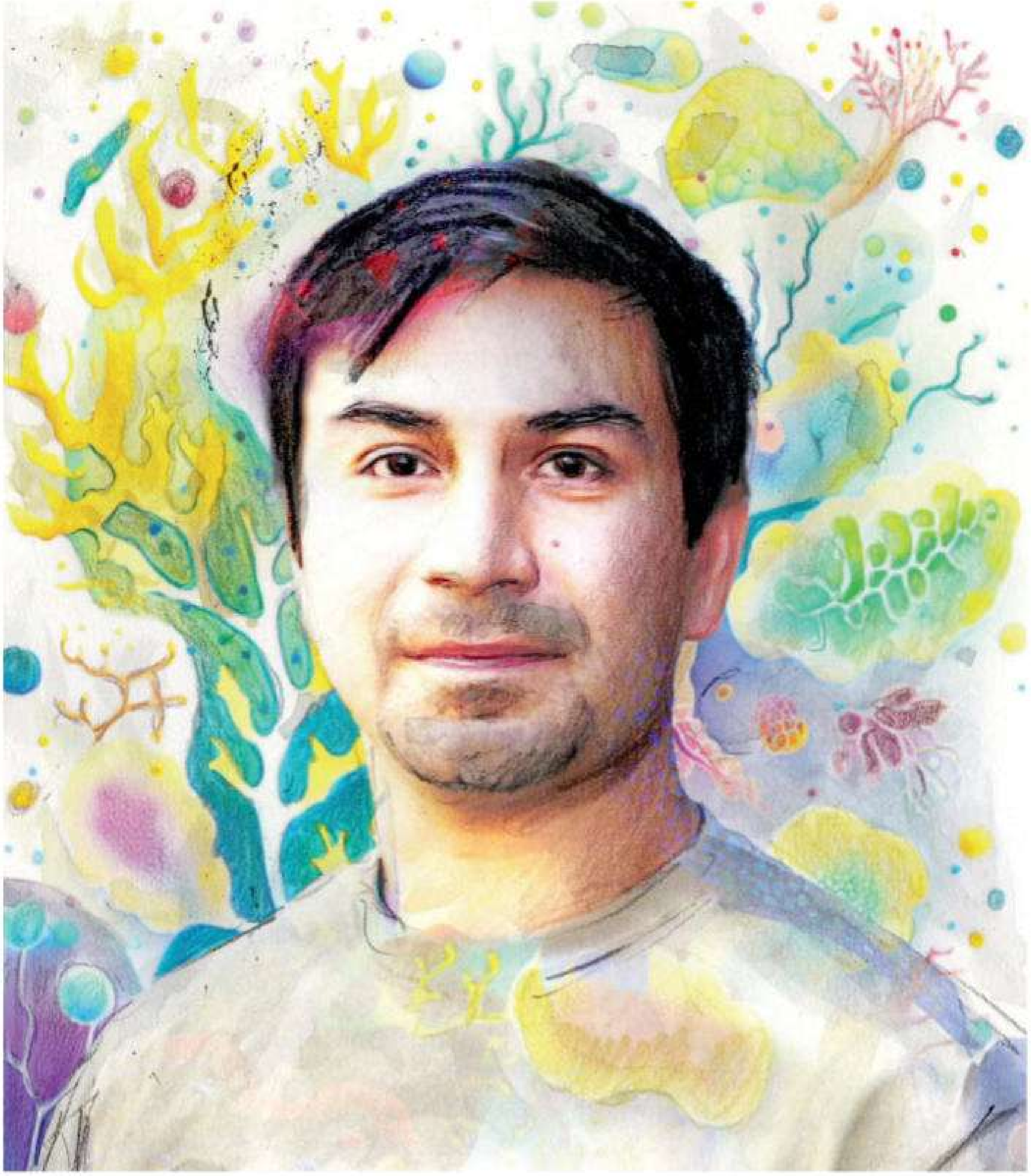
The starting point of another theory, known as loop quantum gravity, is that the fourth force can never be treated like the other three. It is, in a sense, more fundamental. Accordingly, this theory focuses purely on reconciling quantum physics and gravity by proposing that space-time itself has something like an atomic structure. Specifically, it says space-time comes in finite loops, which cling together to create a new stage for reality to play out on called a spinfoam. Loop quantum gravity is a long way from incorporating all of what we know and describe in the standard model of particle physics, and it is no better than string theory at making testable predictions.

TWISTORS

Dating back to the 1960s, twistor theory is very much the underdog among theories of everything. The brainchild of Nobel laureate Roger Penrose, it says that space-time and its force manifestation, gravity – not to mention other fields and particles – are merely the gloss of a deeper reality that consists of chains of cause and effect. Although the chains themselves can never be broken, the apparent location and timing of events within them is variable, so that their full description is something broad and contorted: a twistor.

If that sounds confusing, you are in good company. Twistor theory is so conceptually difficult that even Penrose shies away from explaining it in interviews. But although it has been unpopular for decades, it has experienced a renaissance in recent years, with theorists finding intriguing connections to string theory. ■

Jon Cartwright is a science journalist based in Bristol, UK



NABIL NEZZAR

Family secrets

The Yanomami people's super-diverse gut microbiomes may hold clues to better health. As part of the community, microbiologist **David Good** plans to make sure they benefit from the information, finds Clare Wilson

THE Yanomami people, based in the Amazon rainforest of southern Venezuela and northern Brazil, are one of the last Indigenous groups in the region that still live by hunter-gathering and small-scale farming. They also have the most diverse gut microbiome of any human community studied so far.

David Good is half Yanomami: his mother is a member of the Irokai-teri community and his father is from the US, where Good was brought up. After a life-changing reunion with his mother in the Amazon as an adult, Good is now doing a PhD in microbiology at the University of Guelph in Ontario, Canada. His research involves studying the Yanomami's unusual microbiomes – the bacteria, viruses and fungi that live on and in our bodies – with a view to developing new therapies for microbiome-associated conditions.

Here, he tells *New Scientist* about his work with the Yanomami, from collecting stool samples from family members and gaining first-hand experience of their diverse diet – and why he will never eat armadillo again – to what we can learn from studying their microbiomes.

Clare Wilson: Do you mind if I ask about your family? How did your parents meet?

David Good: Sure. My dad was a grad student at Pennsylvania State University and he was tasked to enter the Amazon to study the Yanomami's protein intake. At the time, in the late 1970s, there was a debate over whether protein deficiency was causing their warfare. [The Yanomami have been falsely portrayed by anthropologists as engaging in a great deal of warfare and violence over access to resources.] He fell in love with the Yanomami way of life: they wake up and they work together as a community to find food. It's not an easy world, but it's a relatively stress-free world. What was supposed to be a 15-month research programme ended up being 12 years in the jungle. And that is where he met my mother, Yarima. They developed a romance and they married according to Yanomami customs.

My dad brought my mom to the US. She adapted and she loved a lot of things about US society, but she became more and more depressed and isolated, because the only person she could talk to in this world was her husband. She made a decision to leave the family and, at 5, I lost my mom.

How did your mother leaving affect you?

I spent the next 20 years grappling with my identity. As a young child, I asked why did my friends have moms that make them peanut butter and jelly sandwiches, but my mom is a naked Indigenous woman eating spiders and monkeys? After I graduated from college, I decided to go on a quest to return to my Indigenous homeland to find my mother. I didn't know if she was alive.

Did you find her?

I met with Hortensia Caballero-Arias, an anthropologist at the Venezuelan Institute for Scientific Research. She and I embarked on this journey together to look for my mother. In 2011, I arrived in the Irokai-teri community, and there was mom. She had the hii-hi sticks that the Yanomami adorn themselves with in her nose and lower lips. I remember she was walking towards me, I didn't speak Yanomami, and she doesn't speak much English. I didn't know what to say.

David Good was reunited with his mother, Yarima, in 2011

DAVID GOOD

Did you recognise her?

Of course, I recognised her from the photos and she looked as beautiful as ever. I just put my arm on her shoulder and said: "Hey Mom, it's me, David, your son. I'm home." I think she recognised that word from when I was a 5-year-old, calling her "Mom". We broke down and started crying.

I knew then and there that I didn't care why she'd left. I decided that I love my mom, I was grateful that she was alive and that I had found her. Now, all I want to do is spend as much time as I can with her. I visit as often as possible. I want to learn about my Yanomami heritage.

Can you tell me what Yanomami culture is like?

Finding food is a big part of the Yanomami way of life, but it's more than just surviving. They do it in a social way – and it's always fun. Everything that they eat is extracted from the surrounding rainforest and the Amazon is a biodiversity hotspot of flora and fauna. Plantain is a big part of their diet, and they grow it in their gardens. They're also opportunistic foragers: if it moves, you can eat it. I've eaten everything from piranhas to monkeys to capybaras, caterpillars, grub worms and so on – things you don't find in US grocery stores.

What is your favourite Yanomami food?

My favourite is boa constrictor. I remember sitting in my hammock one day and my mom came up to me and threw this 2-foot-segment [60 centimetres] of a boa constrictor on my lap and said: "Here, eat some snake." It is meaty, but it has an oily texture as well, like scallops. It's such a yummy meat.

How about your least favourite?

When I had giant armadillo, I had the worst diarrhoea I've ever had for about two or three days. I have not eaten that since.

You are now interested in Yanomami gut bacteria. Why?

The Yanomami have much higher microbial diversity in their guts compared with people ›

> "They think: 'Who is this crazy uncle going around asking for faeces?'"

DAVID GOOD

Good and his colleagues make regular visits to his relatives among the Yanomami

living in Western industrialised societies. My research aims to look at what these "extra" bacteria are doing, given that we now know that many gut bacteria provide nutrients and resources for the cells in our bodies.

Why is the Yanomami's gut microbiome so different?

To start with, our microbiome is harmonised with the world in which we live. In the Western diet, we consume a lot of processed foods containing simple carbohydrates like sugars and refined starches in white bread and rice. This is mainly absorbed in the small intestine. Plantain and some of the other foods that the Yanomami eat contain a lot of fibre and resistant starches, so-called because they resist digestion in the small intestine and pass into the colon to feed the "good" microbes there, particularly *Prevotella* species. People in Western societies, by not providing their gut with the right food, have starved these "good" microbes. But when fed, the microbes produce beneficial metabolites, such as short-chain fatty acids, which help temper inflammation in the human body.

What impact does that have on health?

There are many illnesses that have an inflammatory component – allergies, diabetes, obesity, Crohn's disease, inflammatory bowel disease, cancer. These diseases are rare or absent in the Yanomami. Our research will provide a reference point for the microbiome and human health. I am confident that what we are learning from the Yanomami will benefit us.

Will the Yanomami benefit from this research too?

This is my family and it's really important to get this right. My colleagues and I are working with experts from several disciplines, like anthropologists and bioethicists. We have set up a charity called The Good Project, to advance microbiome research among the Yanomami while promoting their resilience and self-determination, as well as protecting the rainforest. We go above and beyond normal ethical standards by making sure that if there's any commercial viability to this research, there is an agreement in place to ensure a meaningful benefit to the Yanomami people. Because, of course, we are aware that there is a history of biopiracy – exploiting Indigenous people, their knowledge and resources for profit without giving back to them. That's happened to vulnerable populations in the US too. We are determined to set a new standard for this type of scientific research.

There is currently a lot of interest in the idea of gut "rewilding", but would the bacteria found in Yanomami guts thrive on a Western diet?

These microbes co-evolved with the Yanomami for thousands of years. It's hard to imagine getting microbes from a hunter-gatherer society to thrive in someone who lives in New York. What feeds those microbes? Someone in New York is probably not eating monkeys or plantain. Those microbes would probably starve and die out really fast.

Should everyone be living more like the Yanomami?

I'm sceptical of that. I don't think the answer is "Let's all go be naked and run into the forest", because that's not who we are. But I do think there are things we could do. Maybe the answer is looking at the metabolic outputs that the microbes are producing, including the short-chain fatty acids that I mentioned earlier, but also considering the many other as-yet unexplored compounds that beneficial gut bacteria make in response to diet. Perhaps they could be harnessed to temper inflammation or to help with our body's glucose response after eating meals high in sugar or refined starch.

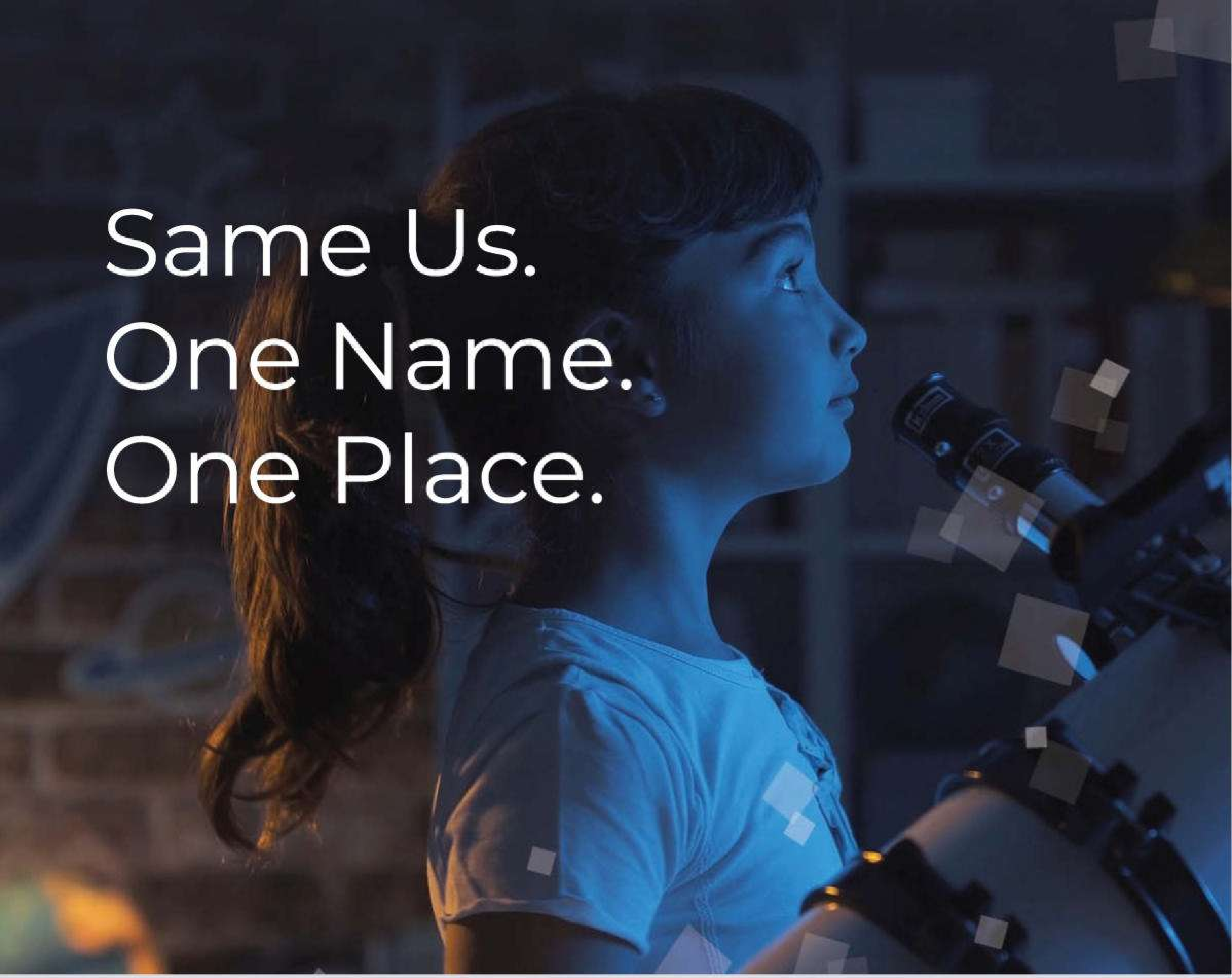
Studying the gut microbiome usually involves looking at faecal samples. How do your Yanomami friends and family feel about your work?

Imagine it. I am a member of their community who has been gone for a while and then come back. Obviously, I engage with them and catch up with them, but then I ask their consent to collect their faeces, and take skin and oral samples. They think: "What is this? Who is this crazy uncle going around asking for faeces?"

How likely is it that this sort of research will lead to medically useful products?

It's fair to say this is an emerging field and we have a long way to go. We are still developing the tools to come up with a cohesive and consistent way to even describe the microbiome. The way one group extracts DNA can be different from how another group does it, and they come up with different sets of data. How can you compare conclusions, if you have different methods and protocols? I am quite new to this, but I think we are making progress and it is a very exciting field to be working in. Every day something new comes out. So far, we have just scratched the surface. ■

Clare Wilson is a health reporter for *New Scientist*. Follow her on Twitter @ClareWilsonMed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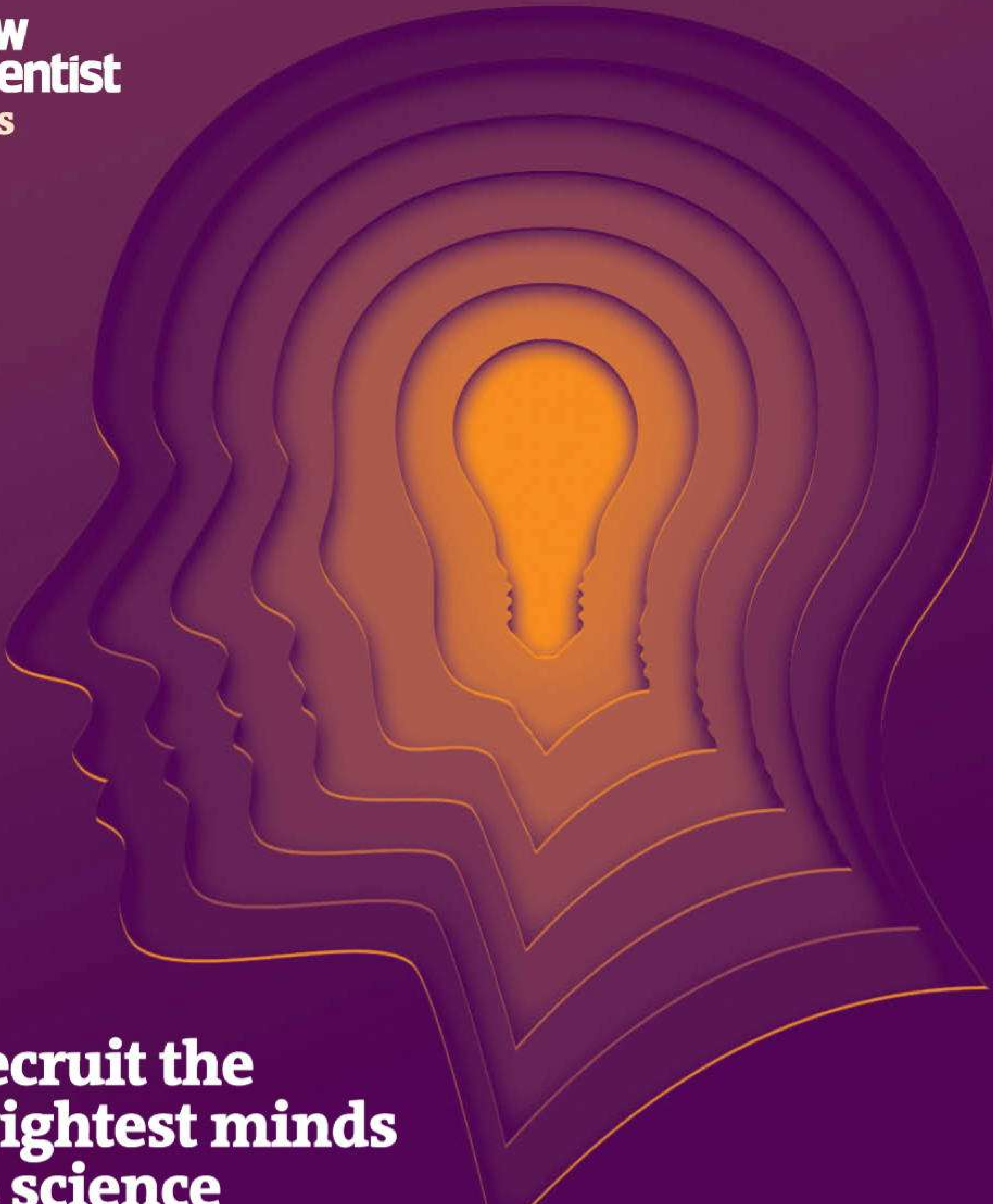

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Feedback
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Twisteddoodles for *New Scientist*
Picturing the lighter side of life p56

Science of gardening

Asparagus tips

Growing asparagus takes time, but your patience will be rewarded with a crop tastier than shop produce, says **Clare Wilson**

Clare Wilson is a reporter at *New Scientist* and writes about everything life-science related. Her favourite place is her allotment garden @ClareWilsonMed

What you need

Asparagus crowns
Patience

Science of gardening appears every four weeks. Share your gardening successes with us on Twitter and Instagram @newscientist, using the hashtag #NewScientistGardening

THERE is much debate about the merits of eating fruit and vegetables that are available seasonally and grown locally, to reduce your carbon footprint. From a taste point of view, I would argue that there are at least two crops where locally grown produce has a real edge. These are strawberries, which have better taste and texture if you can get them fresh, and asparagus – in my humble opinion, the king of vegetables, but also known among growers as the most quickly perishable after harvesting.

For these reasons, it is well worth buying asparagus only during the brief period in spring when it is in season locally and trying to choose produce that looks as freshly harvested as possible. The stems should be firm to the touch and the buds at the end tightly closed.

An even surer way of getting a freshly picked crop is to grow your own. Asparagus is a great choice for beginner gardeners as it is so trouble-free. Unlike many other crops, it doesn't seem to appeal much to slugs or other pests, so I get a brief glut of asparagus every spring.

The only downside is that growing this plant is a long-term investment in good eating. After planting your asparagus "crowns" – an unpromising-looking bundle of roots – you have to wait two or three years before the plants can be harvested.

This is because they need to be strong enough to survive when you brutally snap off the emerging stems to feast on. After about two months of harvesting, you must leave the stems to regrow in peace so they can photosynthesise all summer and send energy down to the roots for next year. That is why the asparagus season is so short.

PIXEL-SHOT/ALAMY

Once allowed to grow, the asparagus stems become huge, feathery fronds – far too tough to eat, but a decorative backdrop for flower beds. The growth stops in autumn and the stems should be cut down in winter, letting the cycle begin again.

As the UK asparagus season is fast approaching – by tradition, it starts on 23 April, St George's Day – I am eagerly monitoring my asparagus bed to spot the first shoots pushing up through the layer of mulch I treated the plants to over winter. The stems can grow as quickly as 10 centimetres a day, so I keep a close watch to make sure I don't miss out on an early harvest.

This high metabolic rate may be why asparagus is so perishable. Once picked, the stems metabolise their sugars in a vain effort to keep growing. There is also a rise in fibrous materials such as lignin, so less-fresh produce is tougher as well as less sweet and delicately flavoured. I am so keen to eat my asparagus fresh that when I visit my allotment, I pick the stems just before I am about to leave and devour them as soon as I get home – briefly steamed and slathered in butter. ▮

These articles are posted each week at newscientist.com/maker

The taming of the kilderkin.

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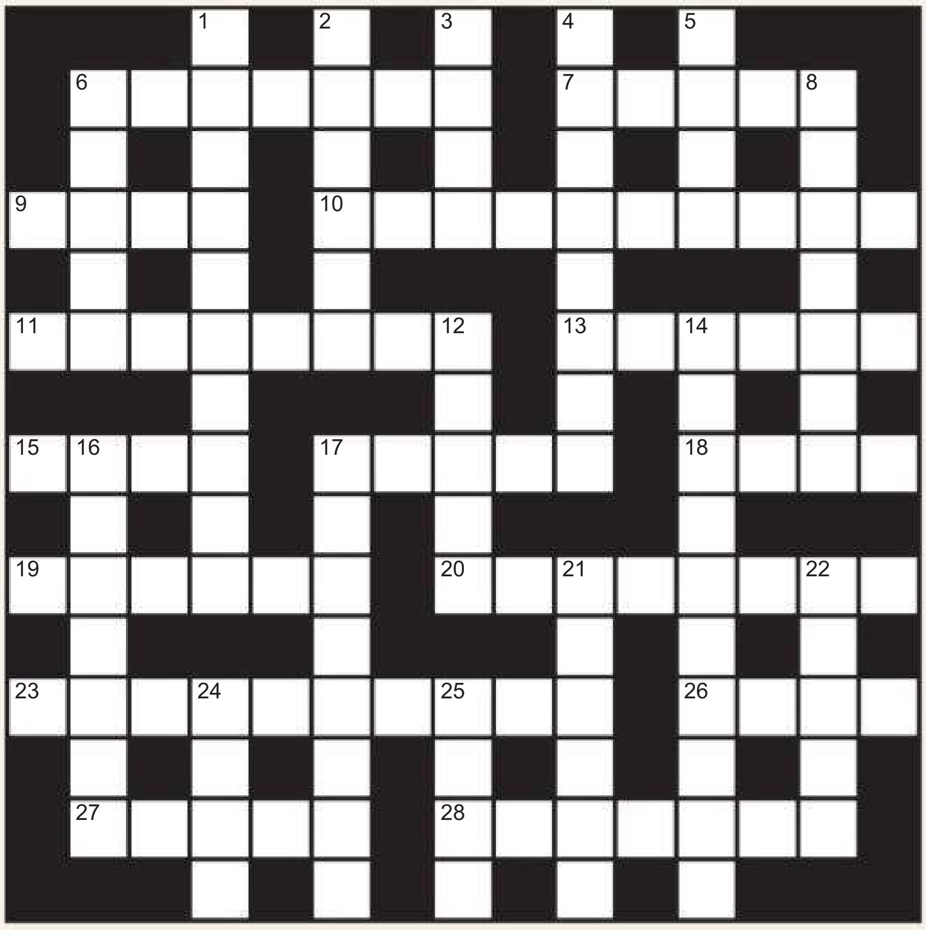
Quick crossword #130 *Set by Richard Smyth*



Scribble zone

Answers and the next cryptic crossword next week

ACROSS

6 Term for the destruction of living systems (7)
7 (Relating to) sound (5)
9 Online journal (4)
10 Tropical woodland (10)
11 Benjamin ___, 18th-century statesman and inventor (8)
13 Shock of contact (6)
15 Datum (informally) (4)
17 Sudden, short-lived rush or increase (5)
18 ___ review, system of academic evaluation (4)
19 Empty (6)
20 Covering of the head of a flower or comet, perhaps (8)
23 1968 science fiction film directed by Roger Vadim (10)
26 Fe (4)
27 Remove glitches (from) (5)
28 Dizzy feeling (7)

DOWN

1 Inborn (10)
2 Term for the left atrioventricular valve (6)
3 Search for extraterrestrial intelligence (4)
4 Stimulant in the methylxanthine class (8)
5 Clément ___, French aviation pioneer (4)
6 Leonhard ___, Swiss mathematician and polymath (5)
8 Tiny bone such as the incus or stapes (7)
12 Axon bundle (5)
14 Papillary inflammation (10)
16 Unit of retinal illumination, abbreviated to Td (7)
17 Infrastructure for effluent (8)
21 Brand name for sildenafil (6)
22 Image created on film (or on an image sensor) (5)
24 Swelling of the lymph node (4)
25 Molten rock expelled from a volcano (4)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #196

set by Bethan Ackerley

1 Pathologist Bert Achong is best known for co-discovering which virus?

2 *Saccharomyces cerevisiae* is commonly referred to by what name?

3 Basophils and neutrophils are types of which cell?

4 The prehistoric Clovis culture was named after a city in which US state?

5 Hawking radiation is thought to be emitted by which objects in space?

Answers on page 55

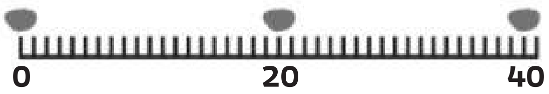
Puzzle

set by Daniel Griller

#216 Game of stones

Let's play a game, dear reader. I have placed three stones on a number line: one on 0, one on 20 and one on 40. You and I shall take the game in turns; on a turn, a player picks up one of the two outer stones and places it on a whole number between the other two stones. The game continues until the stones occupy three consecutive whole numbers, whereupon no further moves can be made, and the game ends. The player who made the final move is the winner.

As the game is played by my rules, I will let you have the first move. I feel compelled to warn you, however, that only perfect play will result in my defeat. So here is your challenge: to play this game of stones and claim victory over its creator.



Solution next week

Turning right

Why are the gears and chain always on the right-hand side of bicycles?

Richard Ellam
Bristol, UK
The short answer is because most people are right-handed.

When the first chain-driven bicycles were designed, around the year 1890, the easiest way to attach the sprocket for the chain on the rear wheel hub was to screw it on. The mating screw threads were made using screw-cutting lathes, and these were (and still are) optimised for right-handed users. This meant it was much easier to cut a right-hand thread than a left-hand thread.

A clockwise movement tightens a right-hand thread and it is obviously desirable that the driving force on a bicycle wheel should tend to tighten, rather than loosen, the sprocket on the wheel.

For this to happen when the bicycle is propelled forwards, it is necessary that the sprocket, and hence the chain, should be mounted on the right-hand side of the frame. There is no particular benefit for a bicycle manufacturer to change this to the left-hand side of the bike, even though modern sprockets tend not to be screwed on. This is because all of the other drive chain components, such as cranks, pedals and dérailleurs, would need to be compatible with a left-hand drive bicycle.

> **“Most of us mount a bike from the left, so having the gears and chain on the right reduces the contact with the oily bits”**

Early chain-driven bicycles were “fixies” that couldn’t freewheel. To brake, the rider had to apply backwards turning pressure to the pedals, so a locking ring was screwed on to the outside of the sprocket to prevent it unscrewing due to this.

If an insect got separated from its colony by hitching a ride in a car, what would happen to it?

DANIEL PRUDECK/SHUTTERSTOCK

This week’s new questions

Insect afar **If an ant or bee ends up far from its colony (perhaps by artificial means such as being carried by a car) what will happen to it?** ***Maria Felicen****, Bristol, UK*

Accent origin **People from all over Europe settled in North America in the 17th century, so how and when did the North American accent develop?** ***John Howes****, Cardiff, UK*

@Doctor_Hutch
via Twitter
Drivetrains swapped sides repeatedly in the 1890s, mainly as a marketing gimmick. I think they settled on the right partly because it was easier to use a right-hand threaded sprocket on the wheel.

Bernard West
Toronto, Canada
So that your sword doesn’t get stuck in the dérailleur.

David Jackson
Gosport, Hampshire, UK
I imagine the chain and gears are on the right-hand side of bicycles due to historical precedent going back millennia.

Until fairly recently, some horse riders would have carried a sword. As these people were mostly right-handed the sword habitually hung over their left hip, as it had to be drawn across the body because of its length, meaning it would be far easier to mount from the left.

Early pedal bikes were probably made for people who were reasonably wealthy and so used to riding horses, which tend to be mounted from the left. Putting the chain and sprockets on the right would also mean that long skirts and floppy trousers wouldn’t rub over the oily bits while mounting. This would quickly have become the standard.

Martin Bide
Westerly, Rhode Island, US
This has to do with right or left-leggedness. Most of us are right-legged, and when mounting a bike, will stand on the left of the bike and swing our right leg over. Having the gears and chain on the right reduces the contact with the oily bits in this process.

The same right leg preference is true for mounting horses. And for both horses and bikes, it helps to have a kerb from which to mount: less height to overcome and the rider avoids stepping into the road to get mounted. The result is that the mounted rider, ready to set off, is facing forward on the left-hand side of the road. So the British habit of driving on the left is entirely logical.

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@JimSteerforth
via Twitter
On motorcycles, the chain is (usually) on the left-hand side because, traditionally, the kick starter was on the right-hand side.

Adam Henry
via Facebook
It isn’t always the case that the chain and gears are on the right-hand side.

Some BMX riders prefer a left-side drivetrain. This is so they can more easily perform glides [slides along a ledge or rail] on their right-side pedal, or crank arm, without causing damage to the sprocket or chain.

Quick flight

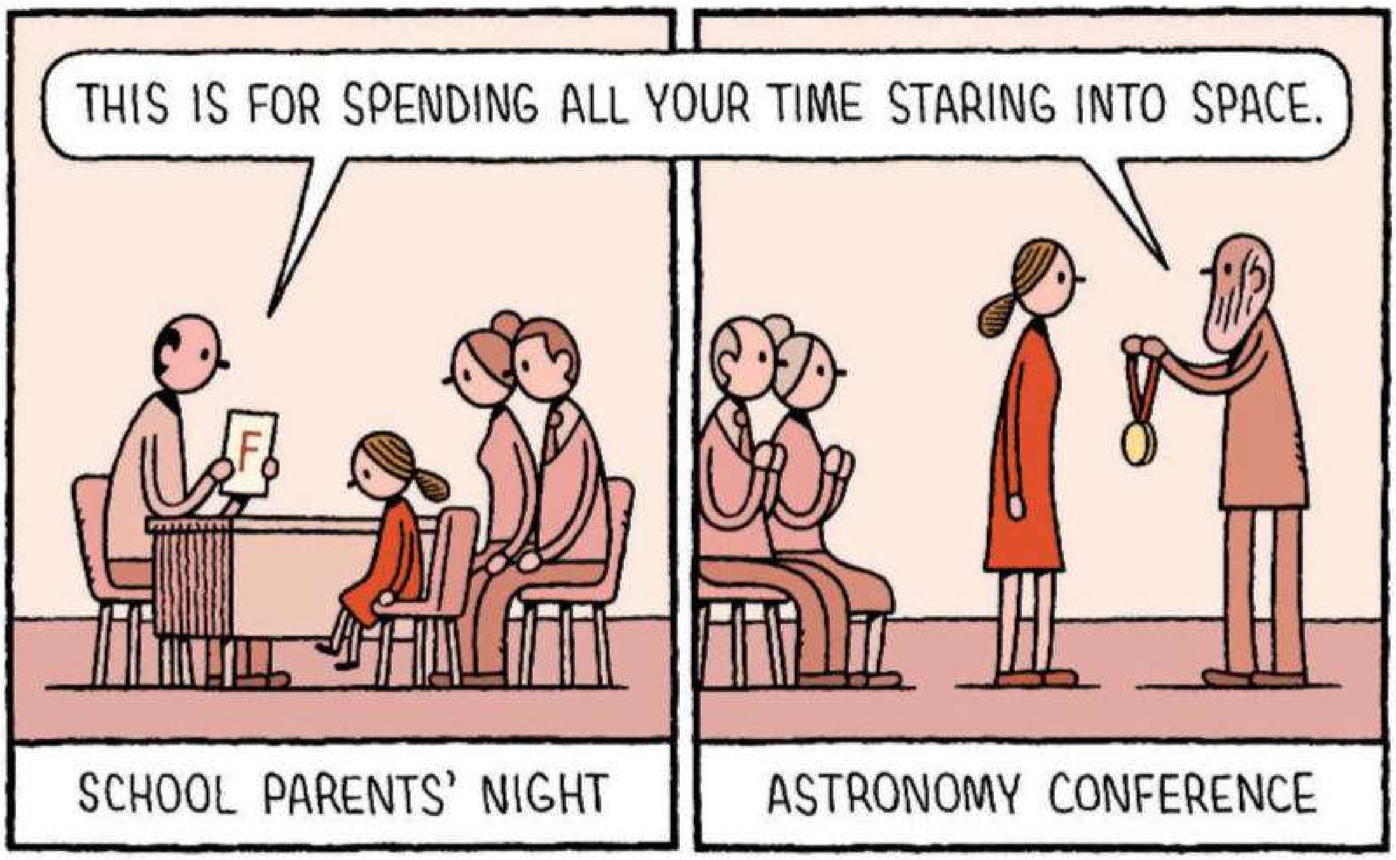
Watching birds in the garden, their reaction times and alertness suggest that their brain processing speed is quicker than ours. Is this correct?

Simon Potier
Foucrainville, France
In general, the speed at which the eyes and brain acquire visual information over time – known as the temporal resolution of vision – is linked to the metabolic rates of an animal, its body mass and the type of food it forages.

Smaller organisms and those with higher metabolic

Tom Gauld

for New Scientist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ASTRONOMY CONFERENCE

rates perceive changes on shorter timescales.

Birds have high metabolic rates, so tend to be faster at discriminating details in a visual scene than humans. Also, as the body size of a bird decreases, its manoeuvrability and metabolic rates increase, as well as the speed of its information processing.

The type of foraging that a bird does is also important for the speed at which it picks up visual information from its surroundings.

It has been shown that species that catch quick-moving prey when flying (such as peregrine falcons, flycatchers and tits) have higher temporal resolution of vision than species relying on seeds (such as budgerigars). A 2016 study of blue tits and flycatchers, for example, found that their ability to perceive visual details was twice as quick as that of humans.

However, the natural world is complex and there are exceptions. Owls, for instance, which hunt moving prey, have relatively slow visual perception speed, whereas that of pigeons, which are seed-eaters, has been shown by some measures to be relatively fast.

> **"Birds such as blue tits and flycatchers that feed on fast-moving prey perceive visual details twice as quickly as humans do"**

John Davies
Lancaster, UK

Birds that fly in flocks, especially murmurations, exhibit exquisite awareness of birds immediately around them, so that they seem to fly as an organised whole.

David Tong
Leeds, UK

Even with the same kind of brain hardware, we might expect a bird that is 5 centimetres tall to react say 40 times quicker than a human that is 200 cm tall, just because the nerve signals don't have to travel as far.

Super tug

I am fascinated by the idea of a tug of war between Dover, UK, and Calais, France, with thousands of people on each side, 42 kilometres apart. Could a rope be made long, light and strong enough for this? (continued)

Mike Tongue
Newark, Nottinghamshire, UK

To stage this tug of war you could actually dispense with a rope that spans the sea between the two countries and instead install a servomechanism – a device that automatically corrects the actions of a mechanism – in Dover and Calais. Each would consist of a winch and load cell. The pull on each load cell would be compared using control software, resulting in rope at each end being pulled in or let out as appropriate.

Previous responses didn't mention Earth's curvature. If a rope were pulled to a straight line between Calais and Dover, at its midpoint the rope would be 40 metres under the sea.

Answers

Quick quiz #196
Answers

1 Epstein-Barr virus, alongside Anthony Barr and Yvonne Epstein
2 Baker's or brewer's yeast
3 Granulocytes, which are a form of white blood cells
4 New Mexico
5 Black holes

Cryptic crossword #106 *Answers*

ACROSS 7 Elytra, **8** Emetic, **9** Taro, **10** Airlocks, **11** Tangled, **13** Speed, **15** Hoard, **16** Teleost, **18** Cerebral, **19** Slew, **21** Dik-dik, **22** Agouti

DOWN 1 Flea, **2** At loggerheads, **3** Manatee, **4** Weird, **5/6** Decompression sickness, **12** Anorexia, **14** Realgar, **17** Crake, **20** Efts

#215 Trivia Tuesday
Solution

Remarkably, the nth day of the nth month will be a Tuesday in four more months in 2023: 6/6, 8/8, 10/10 and 12/12.

In each of the pairs of months April/May, June/July, Aug/Sept and Oct/Nov there are 61 days, and therefore two days later than that (63 days) the date will have advanced by two days and two months.

This is why 4 April, 6 June, 8 August etc fall on the same day of the week every year (though the 2 February never does).

Find the emperor's heart

Holy Roman Emperor Otto the Great certainly wasn't, in the purest medical sense, heartless. But now he is. The search is on to find his missing heart, though it isn't abundantly clear who could lay legal claim to it. It isn't even clear whether the heart still exists.

But maybe it does. And if Emperor Otto's ticker is findable, the folks at the Monastery and Imperial Palace Museum of Memleben, Germany, want you to help them get their hands on it. Behold their invitation.

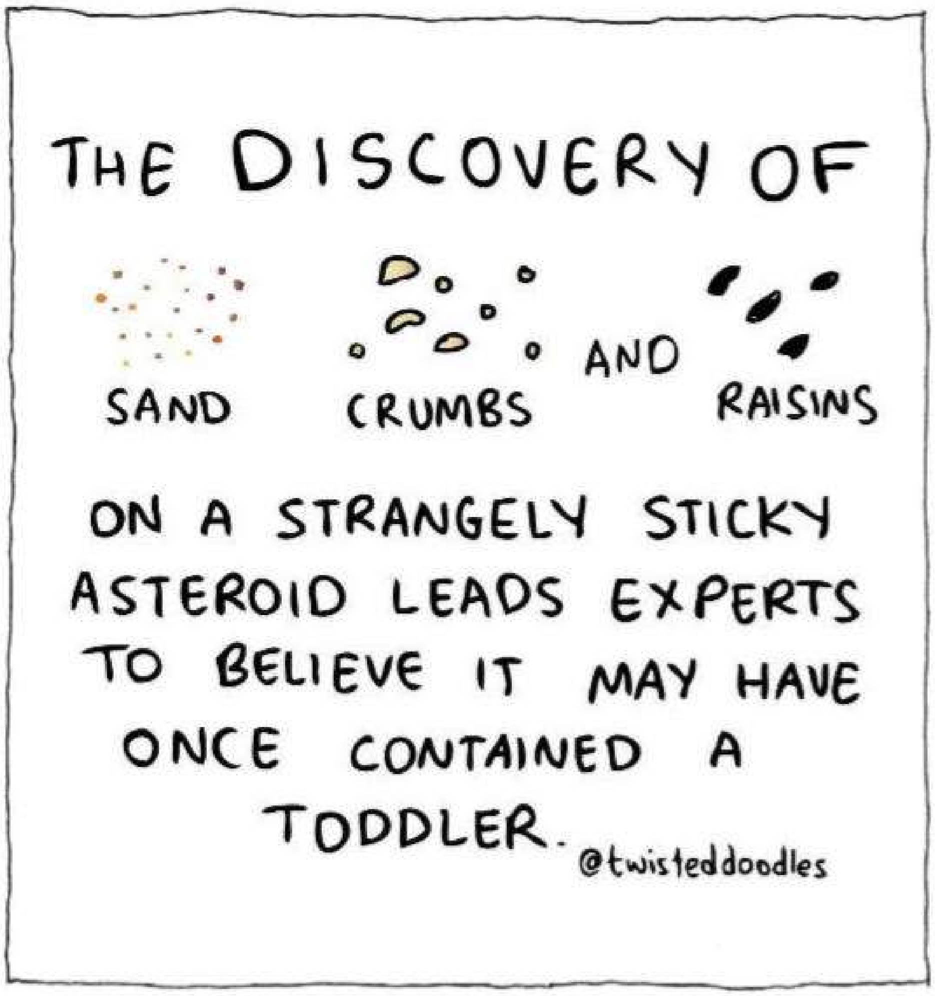
"Emperor Otto the Great died in the Imperial Palace 1050 years ago. His burial took place in Magdeburg, but his heart is said to still rest in Memleben. The Memleben monastery takes its visitors on an exciting deep search for the heart of the emperor."

The Otto heart hunt is a reminder that some body parts do go wandering and that their journeys can be a way of bringing peoples – in whole, as well as in segments – together. Some years ago, historian Andrew Lipman mused on the humanity of this in a paper about the conflict between English colonists and the Algonquian-speaking Pequot people in North America, "'A meanes to knitt them togeather': The exchange of body parts in the Pequot war".

"Algonquian [Native Americans] often exchanged wartime trophies to affirm alliances, whereas the English decapitated enemies and displayed their heads to establish dominance," he wrote. "Because body parts were symbols of political relationships in both cultures, these acts of giving were a way for the two peoples to express and mediate their different notions of authority."

So one sees, in the long run, the potential importance for world peace of finding Emperor Otto's missing heart.

Twisteddoodles *for New Scientist*


THE DISCOVERY OF
SAND
CRUMBS
AND
RAISINS
ON A STRANGELY STICKY ASTEROID LEADS EXPERTS TO BELIEVE IT MAY HAVE ONCE CONTAINED A TODDLER.
@twisteddoodles

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Consideration of items sent in the post will be delayed

Good vibrations

A headline at the website Everyday Health brings vibrant hope for people who feel stuck. It reads: "New drug-free vibrating pill can bring relief for chronic constipation". Lieven Scheire kindly brought this development to Feedback's attention.

Below the headline come these details: "As of this week, doctors can prescribe Vibrant, a first-of-its-kind alternative to conventional laxatives. The patient swallows the capsule, and it makes its way to the colon, where it vibrates to stimulate natural movement in the gut."

Feedback envisions a panel of eminent physicians sitting together on a stage being informed of this development. Each of them reacts by saying not a word. The audience gets to savour the facial expressions of the doctors as they digest this news, their stiff, professional poker-facedness slowly loosening into barely-yet-professionally restrained merriment.

Trivial superpowers

Some trivially superior people answered Feedback's call to help us catalogue trivial superpowers (25 March). A trivial superpower is a person's ability to reliably do some particular task – a task that seems mundane to them, but that most people find impossible to do except once in a while by sheer luck. Here are three super reports.

Paul Clapham says: "I can solve anagrams in cryptic crosswords using subconscious thought. I first noticed this several years ago. A clue suggested the answer was an English author and that it was an anagram of a certain fourteen letters… And then a voice in the back of my head said 'Rudyard Kipling'. And so it was. I notice that ability regularly now, so I don't bother to work so hard on anagrams so much."

John Miller, who is a nurse, says: "I have the ability to do perfect bladder scans. A bladder scan is done with a dedicated ultrasound device. For a number of reasons the actual scan is often not optimal – not central on the bladder, too much pressure on the scanner, changing the shape of the bladder or having the scanner at the wrong angle. Unless it's me scanning your bladder. I will get the scanner in exactly the right place without probing, I just 'know' the best spot on a person. I remember a community nurse trying to scan my partner's bladder with little success. 'Let John do it.' Perfect result."

And Kirsty Greenfield, who is a doctor, says: "I magically know what time it is. I wear no watch, and can be several hours away from a timekeeping device and after recalling the last time I knew the time and what has happened since, I almost invariably can guess the time correct to within 5 minutes. This could be extremely useful but sadly is not, as my superpower becomes unreliable at times of heightened emotion."

Congratulations to each of these gifted individuals for – at least by their accounts – using their trivial powers for good or mundanity, rather than evil.

I see fields of green

The trivially superpowerful Kirsty Greenfield also says, about an unrelated data-gathering enterprise: "I wonder whether any of your other readers have experienced a rather selfish appropriation of nominative determinism of which I believe I have an example? My sister and I, having been born with a shared and unremarkable maiden name, but a deep love of the countryside, both went so far as to marry men with environmentally pleasing surnames. Happily we now have huge amounts of daily contact with our very own small broods of Woods and Greenfields whom we regularly transport around with us." ▮

Marc Abrahams

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